ITALIAN MOUNTAIN GEOLOGY

PARTS I AND II

NORTHERN ITALY AND TUSCANY

BY

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ITALIAN MOUNTAIN GEOLOGY.

PARTS I AND II.

NORTHERN ITALY AND TUSCANY.

PART I. THE PIEDMONTESE ALPS, LIGURIAN APENNINES, AND APUAN ALPS (CARRARA MOUNTAINS).

PART II. THE TUSCAN SUBAPENNINES, INCLUDING THE VOLCANIC GROUPS AND ELBA.

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PREFACE

TO THE THIRD EDITION.

THE present volume is the third edition of Parts I and II, the previous editions having been published in 1917 and 1918. Together with Part III, published in 1923, the volume forms the complete work on the Mountain Geology of Northern, Central, and Southern Italy. Parts I and II deal in succession with the Piedmontese Alps, the Ligurian Apennines, the Apuan Alps or Carrara Mountains, and the Subapennines, including the Tuscan Volcanic Groups and the Island of Elba, while Part III embraces the Gran Sasso d'Italia Group of the Central Apennines, the Volcanic Groups of the Roman and Neapolitan areas, and Mount Etna in Sicily.

The synthetic descriptions of the various groups are the outcome of extensive personal study and observation during ten years of scientific work in Italy, in the course of which I became intimately acquainted with the various regions, the geological examination in the field being greatly facilitated by the excellent maps of the R. Italian Geological Survey. Parts I and II admitted of micro-petrographic details only as far as the limited space allowed, while Part III is accompanied by extensive petrographic notes on the volcanic products of the various groups. A comprehensive petrographic description of the crystalline rocks of Parts I and II, more especially of the great "pietre verdi" groups of Piedmont, Liguria, and Tuscany would in itself constitute a work of considerable magnitude and must be left to the future.

The present volume, Parts I and II, is, like the complementary volume Part III, offered in the hope that it may more widely diffuse the knowledge of, and interest in, the various regions which present an inexhaustible field of fruitful investigation in physical geography and geology, and are, moreover, richly endowed with an infinite variety of natural beauty and historical associations. The complete work is a tribute of my great affection for Italy. In the words of Dante: *D'antico amor sento la gran potenza.*

C. S. Du Riche Preller.

61 Melville Street, Edinburgh.
February, 1924.

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With 27 Illustrations. Part I, 16; Part II, 11.

I.

The Moraine Walls and Lake Basins of Northern Italy.

THE present paper is the outcome of a number of visits which, during a prolonged professional residence in Italy, I paid to Piedmont, Lombardy, and the Italian lakes, and in the course of which I repeatedly examined the glacial phenomena and the lake basins along the southern base of the Alps.

It is forty years—1874 to 1876—since the " Moraine Amphitheatre ", or series of moraine walls at the foot of the Italian Alps, suddenly came into prominence through the discovery, chiefly by Stoppani, of several glacial clay, sand, and gravel deposits in the vicinity of Como, which contained marine shells, and therefore demonstrated the presence of the sea in contact with the Alpine glaciers. Stoppani's conclusions, expounded in two brilliant memoirs,[1] were endorsed not only by his Italian confrères, Spreafico [2] and Sordelli,[3] but also by distinguished geologists north of the Alps, notably by Désor of Neuchâtel,[4] Renevier of Lausanne,[5] and Rutimeyer of Bâle,[6] the revealing memoirs more especially of the two last-named being models of classical and closely reasoned exposition. Since then the subject has been enlarged upon chiefly by discoveries of interglacial deposits in various sub-Alpine valleys debouching into the Lombardy plain, and more recently Penck and Brückner have dealt with it from their point of view in their latest monumental work,[7]

[1] Stoppani, " Il mare glaciale ai piedi delle Alpi " : Rivista Italiana, Agosto, 1874. " Sui Rapporti del terreno glaciale col Pliocenico nei dintorni di Como " : Atti Soc. Ital. di Scienze naturali, Aprile, 1875.

[2] Spreafico, " Conchiglie marine nel terreno erratico di Cassina Rhizzardi (Fino, Prov. di Como) " : Atti Soc. Ital., 1874.

[3] Sordelli, " La Fauna marina di Cassina Rhizzardi, Fino " : Atti Soc. Ital., 1875.

[4] Désor, Le Paysage morainique et son origine glaciaire, Neuchâtel, 1875.

[5] Renevier, " Rélations du Pliocène et du Glaciaire aux environs de Côme " : Bull. Soc. Géol. France, sér. III, tome IV, 1876.

[6] Rutimeyer, Ueber Pliocän und Eisperiode auf beiden Seiten der Alpen, Bâle, 1876.

[7] Penck and Brückner, Die Alpen im Eiszeitalter, 1909. Penck's well-known four glacial periods in relation to the Alps *en bloc* (the Gunz, Mindel, Riss, and Wurm, the last followed by minor stages and oscillations) correspond to the more acceptable because more general Swiss denominations of Pliocene and Pleistocene glacial and fluvio-glacial products, i.e. Upper and Lower Deckenschotter, and Upper and Lower Terrace Gravels respectively. Penck's divisions have been in the main adopted by Italian glaciologists, notably by—

T. Taramelli, " L'Epoca glaciale in Italia " : Atti soc. ital. progr. delle scienze, Roma, 1910, p. 253.

V. Novarese, " Il Quaternario in Val d'Aosta " : Boll. R. Com. Geol., pts. i–iii, 1911, p. 251 ; 1913–14, p. 203 ; 1915, p. 137.

F. Sacco, " I Ghiacciai antichi ed attuali delle Alpi Marittime centrali " : Atti soc. ital. sc. nat. Pavia, 1912, p. 99.

whose salient features have been summarized by G. W. Wright.[1] But this interglacial evidence adduced by the various Italian and other writers is as yet incomplete, and often so conflicting that it is almost refreshing to turn to the earlier and more conclusive views of Stoppani and his contemporaries as a point of departure for considering the subject *mutatis mutandis*, in order to arrive at some independent conclusions from personal observation.

I. The Moraine Walls.

As will be seen from the sketch-map, Sheet No. 1, Fig. I, the belt of double, in many places triple, concentric moraine walls which fringes the southern base of the Alps, forms roughly a semicircle extending from Cuneo in the south of Piedmont to Lake Garda in Lombardy, a distance of about 400 kilometres, and from the last-named point to the Frioul, another 200 kilometres. The most striking feature of this belt consists not only in its remarkable extent, but in the enormous accumulations of glacial material, compared with which the morainic deposits north of the Alps, notably in Switzerland, almost sink into insignificance. The moraine walls were all formed, like so many bars, in front of the exits of the principal valleys. Thus, near Cuneo we find the terminal moraine of the Stura glacier; west of Savigliano, that of the Po (Monte Viso); at Rivoli, near Turin, that of the Dora Riparia (Mt. Cenis); at Ivrea that of the Dora Baltea (Mt. Blanc and Mte. Rosa); at the lower end of Lakes Maggiore and Varese, that of the Ticino and Toce (St. Gothard and Simplon); near Como and Lecco that of the Adda; at the lower end of Lake Isco that of the Oglia; and at Lake Garda the terminal moraine of the Mincio glacier.

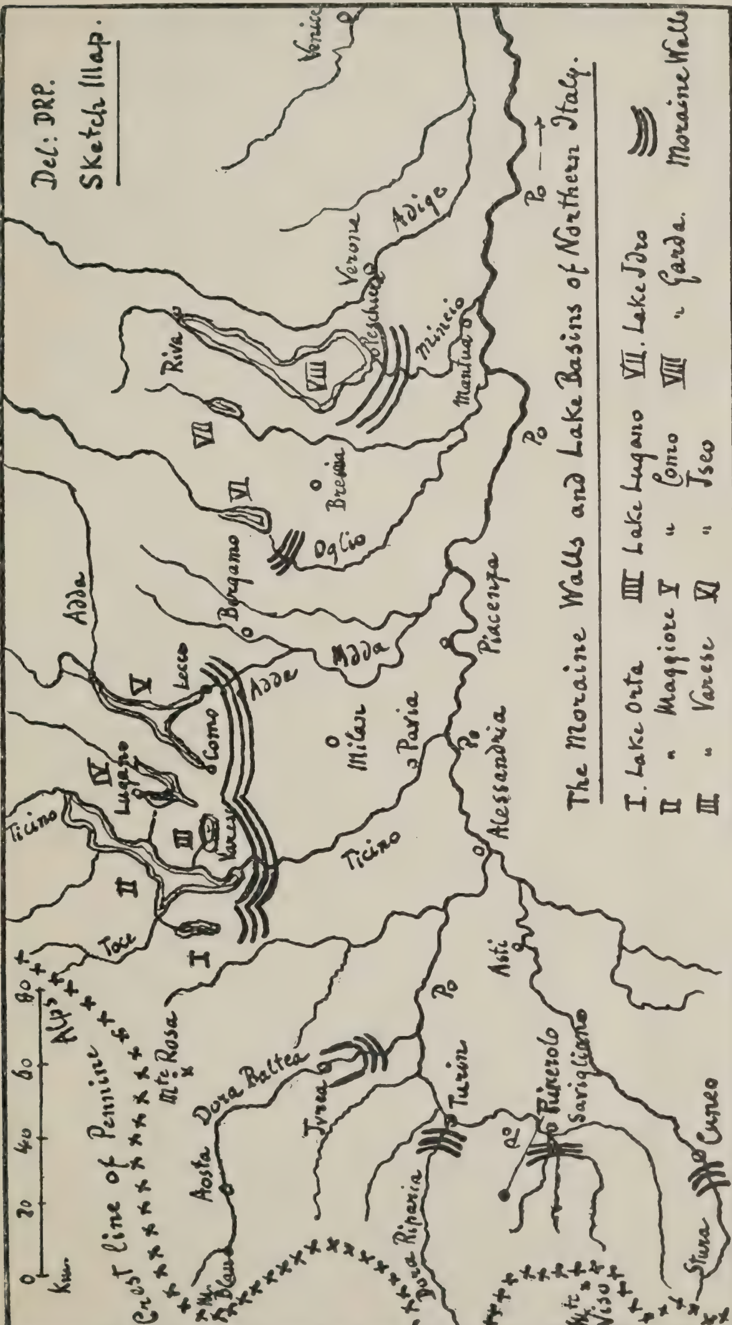
The most formidable of these moraine walls are those of Rivoli, Ivrea, and at the lower ends of Lakes Maggiore, Como, and Garda. The Mt. Cenis glacier, which filled the Dora Riparia Valley, deposited enormous banks of morainic material, more especially at its terminal fan in the great horseshoe or amphitheatre of Avigliana, where the deposits on the semicircular heights reach up to 900 metres altitude, or 500 above the valley floor, and thence expand to Rivoli and down to the Po plain near Turin, in a distance of over 20 kilometres, with a frontal circumference of at least 40 kilometres.[2] Again, in the great glacial amphitheatre of Ivrea—50 kilometres north of Turin—the combined Mt. Blanc and Mte. Rosa, in part also the Gran Paradiso glaciers descending through the lower Dora Baltea Valley, have left two stupendous marginal moraine walls, the "Serre" of Andrate and Brosso, which reach a height of 450 metres above the present river-level, and, with the frontal moraine broken up into hillocks and interspersed with morainic lakelets, form

[1] G. W. Wright, The Quaternary Ice Age, 1914.

[2] These glacial deposits were described in detail by Professor F. Sacco in "L'Anfiteatro Morenico di Rivoli": Boll. R. Com. Geol., 1887, p. 141.

Sheet No. 1. Sketch-map of Northern Italy.

Fig. I.



a circumference of at least 50 kilometres. Again, south of Lakes Maggiore and Varese, the concentric moraine belts of the Ticino and Toce glaciers extend to 10 kilometres from the lake-end, with a circumference of 50 kilometres and a height of 150 metres above Lake Maggiore. South of Como the moraine deposits form, in a distance of barely 10 kilometres, three separate concentric ridges about 20 kilometres in length, rising to 152, 157, and 165 metres above the level of Lake Como. Similarly, at the lower end of Lake Garda, the moraine walls extend in concentric semicircles and an extraordinary agglomeration of morainic hills 12 kilometres into the Lombardy plain, with a circumference of at least 30 kilometres, and rising to 23, 62, and 141 metres above the lake-level.

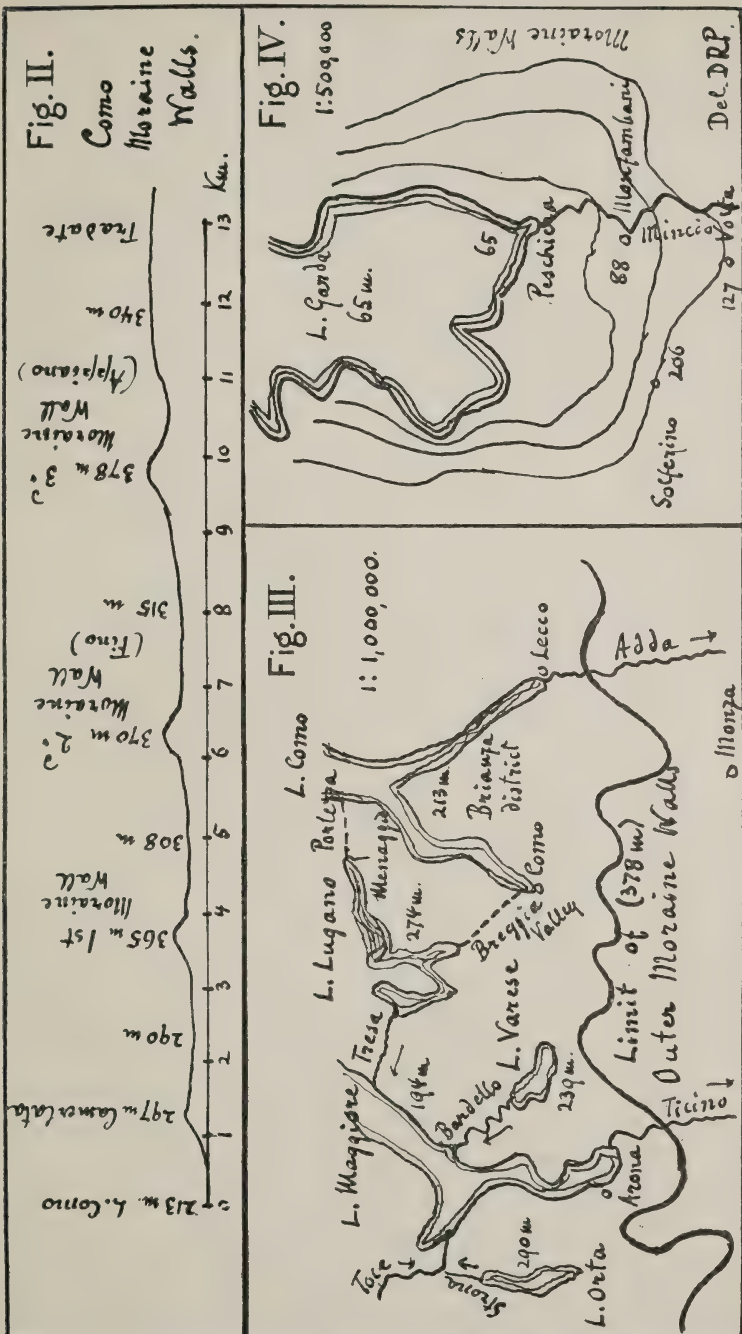
The points where marine shells were found embedded in glacial deposits are situated about 6 kilometres south and north-west of Como ; the former near Fino, on the second of the three concentric moraine ridges, about 160 metres above the present lake-level, and the latter between Chiasso and Mendrisio in the Breggia Valley, by which the former Lugano fiord communicated with that of Como.[1] The most northerly of the latter deposits is that of Pontegana, near Balerna, about 90 metres above the present lake-level, which, being glacial clay, corresponds to similar deposits near Varese, and to others in the Ivrea district. In Lombardy the shell-bearing deposits rest directly on Pliocene marl and are overlain by morainic material of sand, gravel, and conglomerate, known as ceppo and ferretto, while in Western and Southern Piedmont many of the glacial deposits exhibit intermediate fluvio-glacial alluvia, whose origin was at the time a subject of keen controversy between Stoppani and Gastaldi. These alluvia are, in fact, the southern equivalent of the "alluvion ancienne" and Deckenschotter north of the Alps, and, as such, the product of a pre-maximum glaciation which in Upper Piedmont, but not in Lombardy, reached to the foot of the Alps. As regards the stupendous Moraine Amphitheatre of Piedmont and Lombardy as a whole, it can only be the product of the maximum glaciation, while any pre-maximum, as also the post-maximum or last glaciation, probably did not descend much beyond the heads of the present lakes, or, roughly, beyond a limit 30 to 40 kilometres distant from the Lombardy plain.[2] The extreme limit of the maximum glaciation, as indicated by the outermost moraine walls 10 to 12 kilometres south of the lower ends of the Lakes Orta, Maggiore, Como, and Garda, is shown in Sheet No. 2, Figs. II, III, and IV.

[1] Most of these deposits are now obliterated, but ample specimens of the marine shells are preserved in the Geological Museum of Milan.

[2] The principal localities of interglacial deposits between Lakes Maggiore, Lugano, and Garda, and beyond are the following: at Re, in the Vigezzo Valley, east of Domo d'Ossola ; at Calprino, near Lugano ; at Leffe and Gandino in the Seriana Valley, north of Bergamo ; at Pianico in the Oglio (Lake Isco) Valley ; at Valmarino in the Piave Valley, north of Treviso ; in the Tagliamento Valley, north of Udine ; and in the Isonzo Valley, north of Gorizia.

Sheet No. 2. Moraine Walls.

Figs. II, III, IV.



II. The Glaciers and the Sea in the Po Valley.

The maximum glaciation south of the Alps presents a striking contrast to that on the north in that it was marked by a uniform general advance of more or less self-contained glaciers of the fan or Piedmont type, which invaded the Po Valley to a distance of 10 to 12, in the case of the Dora Baltea (Ivrea) glacier even 20 kilometres, while north of the Alps the glaciers spread all over the Swiss lowlands and deposited their terminal moraines even beyond. Thus the maximum length of the southern glaciers, measured from the crest-line of the Alps to their terminal moraine walls, does not exceed 100 kilometres, while on the north the Rhone and the Rhine glaciers, extending beyond the Jura and Lake Constance respectively, reached a length of 300 kilometres, or three times as much. Inversely, the quantity of material carried and deposited by the southern glaciers having an average fall of 1 in 100, was immensely greater than that of the northern glaciers, the average fall of which was only about half the above. Hence the enormous accumulations of glacial material in Piedmont and Lombardy, where, moreover, the glaciers on emerging from the valleys were arrested by the sea as an effectual barrier to their further advance into the Po Valley. This Upper Pliocene sea, an arm of the Adriatic, must have lasted well into the Pleistocene period, and the glaciers washed by it must have been stationary for a very long lapse of time, as is shown by the double and triple concentric frontal moraine walls, each of which marks a long halt in the slow retreat of the ice.[1] No less certain is it that the sea must have been at a level much higher than the present Po Valley, and higher even than the present levels of the lakes, for the Pontegana marine shell-bearing deposit in the Breggia Valley north of Como is at 300 metres altitude, which is 87 metres above Lake Como, 197 metres above Milan, and 240 metres above the Po at Piacenza, while the Fino deposits south of Como are at an altitude of even 370 metres. It is therefore obvious that at the advent of the maximum glaciation, arms of the sea reached as far as the fjords which constitute the present lake basins—a phenomenon which has an important bearing on the age and origin of the lakes themselves.[2]

III. The Lake Basins.

The following table gives the altitudes and dimensions of the principal six Italian lake basins, which, it will be observed, lie in a zone similar to that of the five Swiss lake basins north of the Alps.

[1] It is a striking feature that, of the moraine walls, those of the Como district are continuous, because the Adda eroded its bed marginally from the Lecco arm of the lake, whereas the rivers of Ivrea, Lake Maggiore, and Lake Garda (Dora Baltea, Ticino, and Mincio) found their exit more through the centre of the frontal moraines, which are therefore broken up into agglomerations of hillocks.

[2] V. Novarese, op. cit., assigns the bulk of the great morainic amphitheatre of Ivrea, and therefore the maximum extension of the Dora Baltea glaciers, to the Wurm period or fourth glaciation; but, in my view, the maximum glaciation not only north but also south of the Alps was the Upper Terrace, formerly regarded as the second, now as the third (Riss) glaciation.

Lake.	*Altitude.* m.	*Length.* km.	*Mean Width.* km.	*Area.* sq. km.	*Greatest Depth.* m.	*Exit River.*
Orta . .	290	12	2	20	300	Strona.[a]
Maggiore .	194	60	4	212	372	Ticino.
Varese . .	239	9	2	14	380	Bardello.[b]
Lugano . .	274	22	2	83	300	Tresa.[c]
Como and Lecco	213	48	3	144	409	Adda.[d]
Isco . .	201	25	2	62	600	Oglio.
Garda . .	65	55	6	490	346	Mincio.

[a] Drains into Toce, affluent of Lake Maggiore ; [b] drains into Lake Maggiore ; [c] ditto ; [d] exit through Lecco arm.

It will be seen that not one of these lakes reaches the altitude of 300 metres, which, as previously shown, is that of the marine shell-bearing deposit a few kilometres north of Como, nor the altitude of the Fino deposits (370 metres) on the second moraine wall south of Como. The sea in the Po Valley must therefore have communicated with the fjords at a level much higher than that of the present lakes.

The question of how and when the present lakes were formed is obviously and closely allied with the retreat of the sea from the Po Valley. Désor [1] held that from the time of the glaciers coming into contact with the sea the littoral of the Lombardy and Piedmont plain was gradually raised ; but this would only account for the high level of the Fino and the other marine shell-bearing deposits. It appears much more likely that a simultaneous lowering took place on the one hand in the floor of the Po Valley,[2] while the sea gradually receded, and on the other along the base of the Alps, which converted the fjords into lakes in addition to the fjords being choked by the moraine bars of the retreating glaciers. The formation of the lakes would, therefore, be due to the same two concurrent causes which operated in the formation of the lake basins north of the Alps—a zonal flexure and a moraine barrier behind which the river valleys or fjords became lakes during the recession of the glaciers.

The cross-section of the triple moraine walls south of Como shown in Sheet No. 2, Fig. II, exhibits a striking reverse dip from the outermost wall to Lake Como of no less than 165 metres. The third moraine wall, which rests upon considerably bent strata of Molasse, thus constitutes, in my view, the anticline of the flexure whose syncline to the north follows the deepest points of the lakes, while the syncline to the south lies along the lowered floor of the Po Valley. The conditions in respect of Lake Maggiore and of Lake Garda are precisely similar, the reverse dip to the former being 150 and to the latter 140 metres. The two last-named lakes afford, moreover, at their lower ends, typical examples of the formation of

[1] Paysage morainique, p. 72.

[2] The deposition of the rich alluvia which cover the floor of the Po Valley, and to which it owes its wonderful fertility, began with the retreat of the glaciers when the rivers resumed their erosive energy, and continued throughout the long interglacial period after the maximum glaciation.

lake basins behind the terminal moraines of retreating glaciers, for in both cases the widened basins at the lower ends are appendages of the original fjords, and their contours conform strikingly to those of the concentric moraine walls behind which they were formed.

The zonal flexure also accounts for the extraordinary depth of the present lake basins as the result of overdeepening by the lowering of their floors, as against the theory of overdeepening by the direct action of glacial erosion. The latter is the more improbable as, on obvious mechanical grounds, such steep, long, and narrow basins cannot be formed by the vertical scooping of a glacier in the same way as a gradually widening cirque or corrie. The indirect action of the glaciers was more probably confined to the widening of the fjords and of the tributary valleys of the Dora Baltea, Ticino, Adda, and others.[1]

The simultaneous operation of the zonal bending and the retreat of the glaciers on the one hand, and the recession of the sea from the Po Valley on the other, must have been of very long duration, probably till the end of the Ice Age, including the period of the last glaciation, which did not reach, and therefore did not directly affect, the contact zone of the sea and the moraine walls in the Po Valley.

The deposition of enormous quantities of morainic material by the glaciers, followed by erosion and retransport during and after their retreat, produced extraordinary physiographic changes, more especially in the basins of the present Lakes Como, Lugano, Maggiore, and Orta. Among these changes are notably the following: the natural exit of the Como fjord to the south was choked and its drainage reversed, so that the present lake has its only exit through the Lecco arm ; the former connexions between the Como and Lugano fjords at Menaggio and Porlezza, and through the Breggia Valley at Chiasso, were severed by the lowering of the fjord levels, while the Lugano fjord found a new exit through the Tresa into Lake Maggiore ; Lake Varese, too, had its drainage reversed into Lake Maggiore ; and, similarly, Lake Orta had its southern outlet barred and its drainage reversed to the north into the Toce, an affluent of the Lake Maggiore basin. All these phenomena, showing a general drainage reversal from south to north, as well as the labyrinth of erratic and tortuous watercourses throughout the morainic littoral and the whole lake district, are only some of the direct and indirect effects of that great maximum glaciation which has left its impress along the base of the Italian Alps both in Piedmont and Lombardy by a morainic landscape in magnitude, grandeur, and variety unequalled in any other part of the Alps or of Europe.

[1] This view has recently been confirmed also by Professor Taramelli in relation to the Lake Maggiore or Verbano basin, which, forming a trough along the contact line of Upper Palæozoic and crystalline schist formations, was widened in part by fluviatile, in part by glacial erosion, neither it nor the other Italian lake-basins being due exclusively to glacial erosion. T. Taramelli, "Sulla tectonica del Verbano": Rend. Ist. lomb. Milano, 1912, p. 1020.

II.

The Permian Formation in the Alps of Piedmont, Dauphiné, and Savoy.

I. Introductory.

In a paper on the Marble District of the Apuan Alps or Carrara Mountains [1] I showed that the gneissose schists which form the nucleus of that range, and upon which rests the Triassic marmiferous formation, are, not of Archæan, but, upon irrefutable palæontological evidence, of Palæozoic age, and that, upon equally conclusive lithological and stratigraphical evidence they must be assigned to the later part of that period, that is, to the Lower Permian. The former conclusion was first arrived at in the course of the geological survey of the range by Lotti and Zaccagna and upon the palæontological authority of the late Professor Meneghini: the latter conclusion was chiefly the result of the striking analogy, first pointed out by Zaccagna, between the stratigraphical sequence and lithological characteristics of the Apuan Alps and the Montgioie range of the Maritime Alps which forms the divide between Southern Piedmont and the Western Italian Riviera.

The geological survey of the Montgioie range, carried out in the 'eighties, was subsequently extended to a revisionary survey of the Italian side of the Cottian, Grajan, and Pennine Alps for the completion of the new geological map of Italy then in course of preparation and published in 1896; but the latter survey, by Zaccagna and Mattirolo, revealed such fundamental differences between the Italian interpretations and the existing maps of the French side of the Alps that it had, in its turn, to be extended to the French border districts.[2] In the result Zaccagna's conclusions, fortified by his experience in the Apuan and Maritime Alps, were fully confirmed as regards the continuity of the Permian formation from the Maritime Alps to the Western Alps on the French side, a great part of which was until then regarded by French geologists as of much more recent, that is, of later Mesozoic age.

[1] No. X of this volume.

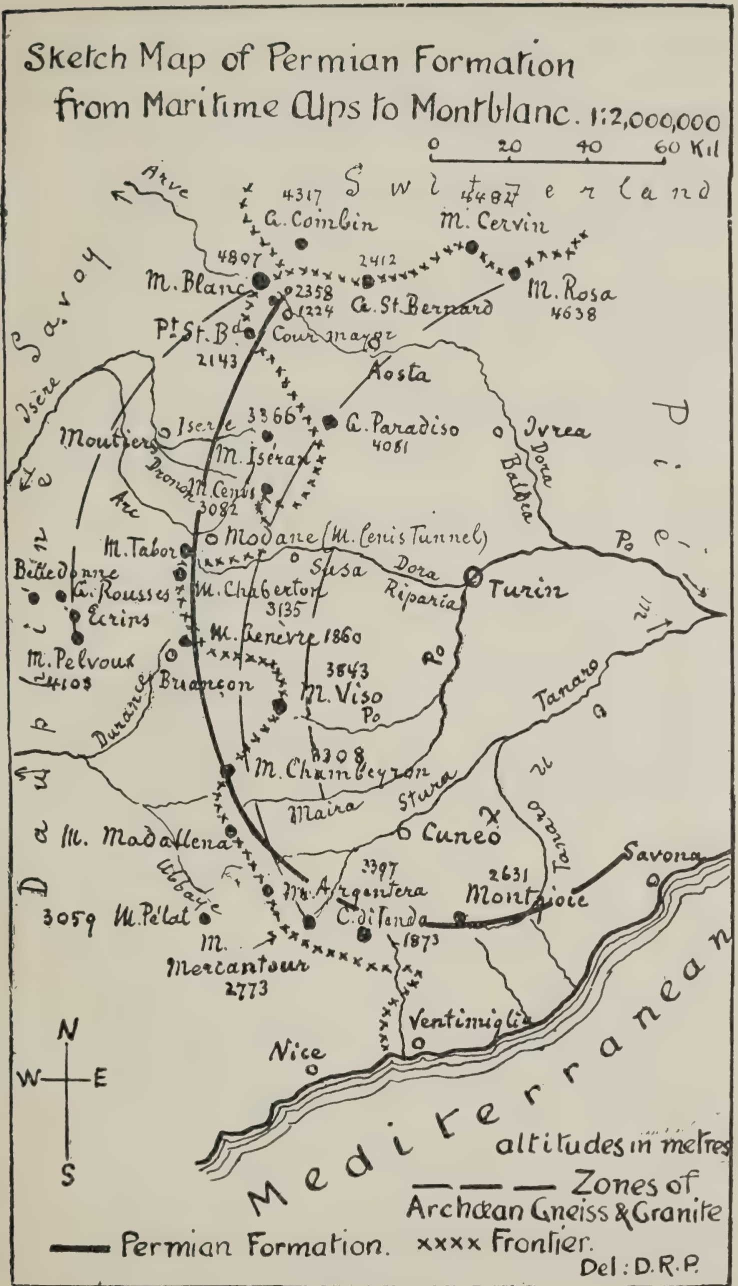
[2] These surveys, accomplished in four consecutive short summer seasons, and embracing the Maritime and the whole of the Western Alps, including the Mont Blanc massif on both sides, constituted on Zaccagna's part a veritable *tour de force*, enhanced by his exhaustive reports in the Bollettino R. Com. Geol. d'Italia of 1887, pp. 346–417, and 1892, pp. 173–244 and 311–404, with maps and sections. He also compiled, with Issel and Mazzuoli, an excellent geological map 1 : 200,000 of the Ligurian and Maritime Alps for the Italian Alpine Club in 1887. The circular examination of the Mont Blanc massif was carried out by Zaccagna himself, while a section from the Arve (Chamounix) Valley across Mont Blanc by the Col du Géant to the Dora Baltea (Aosta) Valley was taken by Mattirolo.

Having visited the Piedmontese, Dauphiné, and Savoy Alps on several occasions, both then and more recently, I propose to succinctly review the main features of the Permian formation in the principal localities, and also to refer briefly to some of the other important points elucidated by the Italian revisionary survey on the French side of the Alps. (See sketch-map, p. 11, and plan and sections, p. 13.)

II. The Permian in the Maritime Alps.

As shown in the sketch-plan (Fig. 1, p. 11), the Italian Maritime Alps, embracing the Ligurian and the Montgioie ranges, extend from Savona west to the River Tanaro, and thence to the Col di Tenda, beyond which lie the Mercantour or Argentera gneiss and granite massif and the Cottian Alps. The Montgioie range, in which the Permian formation reaches its maximum development, comprises in a length of about 50 kilometres between the Tanaro—an affluent of the Po—and the Col di Tenda road a remarkable series of rugged and peaked mountains of an average elevation of 8,000 feet, separated by passes up to 3,000 feet above sea-level. The highest mountain is Montgioie, 2,630 metres altitude, situated practically in the centre but both on the north and the south the crest-range is flanked by a parallel range of somewhat lower elevation.

The Permian formation occupies, in a width of about 40 kilometres, the greater part of the central and also of the northern subsidiary range, the declivities of both being deeply eroded by the Tanaro and its tributary torrents. On the east the formation thins out towards the hills above Savona, and on the west crosses the Stura Valley, whence it passes into Dauphiné. The southern subsidiary range comprises Monte Abisso, Monte Rocchetta (2,473 metres altitude), and some deposits south of Col di Tenda, as part of the Permian formation, but is chiefly composed of Triassic and Liassic strata bordering on a large area of Eocene albarese limestone and macigno sandstone which reaches to the Riviera seaboard of San Remo. Besides Rocchetta and Montgioie, the most remarkable Permian mountain is Monte Besimauda, 2,404 metres altitude, which is entirely composed of that formation and with its double-peaked summit is a conspicuous object as part of the northern subsidiary range, being situated about 20 kilometres south of Cuneo and 10 kilometres east of the Col di Tenda road. The Permian formation, overlying the Carboniferous, may be conveniently studied in the outcrops of those and other mountains, more especially in the deep and narrow valleys of the upper Tanaro and its affluents, one of the most interesting and accessible of which is that of the Negrone torrent on the southern flanks of Montgioie, where the sequence of strata can be distinctly traced on both sides. Another instructive locality is that of the ravines of the Bormida torrents east of the Tanaro and south of Monte Settepani, where the contact of the Carboniferous and the Permian is well exposed at several points.


Sketch Map of Permian Formation
from Maritime Alps to Montblanc. 1:2,000,000
0 20 40 60 Kil
Switzerland
Savoy
Dauphiné
Piedmont
Mediterranean
Arve
4317
G. Coimbin
4807
M. Blanc
2358
1224
Pt St. Bd
2143
Courmayeur
2412
G. St Bernard
4482
M. Cervin
M. Rosa
4638
Aosta
3366
G. Paradiso
4061
Ivrea
Isère
Moutiers
Isère
M. Iséran
Dora Baltea
Arc
M. Cenis
3082
Modane (M. Cenis Tunnel)
M. Tabor
Belledonne
G. Rousses
Ecrins
M. Pelvoux
4103
M. Chaberton
3135
Susa
Dora Riparia
Turin
Po
M. Genèvre 1860
Briançon
Durance
3843
M. Viso
Po
Tanaro
3308
M. Chamberyron
Maira
Stura
Cuneo
M. Madallena
Ubaye
3059
M. Pélat
M. Mercantour
2773
3297
M. Argentera
C. di Tenda
1873
2631
Montgioie
Savona
Tanaro
Ventimiglia
Nice
N
W
E
S
altitudes in metres
Zones of Archæan Gneiss & Granite
Permian Formation.
xxxx Frontier.
Del: D.R.P.

Up to the 'eighties the principal authority on the Maritime and Western Italian Alps was Gastaldi, who, besides his well-known studies on the crystalline and pietre verdi rocks and an unpublished map of the latter Alps, left a memoir on the former.[1] He was at first disposed to class the gneissose schists of the Montgioie range with the Archæan gneiss of the Western Alps; but the Montgioie schists, owing alike to their "deficient crystallinity" and to their stratigraphical location, presented so puzzling a phenomenon that, pending further definition, he designated them as of indeterminate age under the name of "apenninite", as being akin to the Apennines rather than to the Alps. As this formation does not extend east beyond the Savona hills and the Voltri group in Western Liguria, and is in no sense characteristic of the Apennines generally, the name was obviously a misnomer, and hence Zaccagna, who was the first to recognize its true stratigraphical position, chose the name of besimaudite, from Monte Besimauda already referred to, as typically representative of the gneissiform schist, which has its equivalent facies both in the Apuan and the Western Alps, and also in the so-called Suretta gneiss of the Splügen Pass.

The Permian formation reaches a thickness of at least 1,000 metres, and rests directly and conformably upon the fossiliferous Carboniferous strata, which attain about half that visible depth and constitute the lowest zone of the Montgioie range. The latter strata are, as usual in the Alps, composed in the main of blackish carbonaceous and grey micaceous schists, graduating into talcose greenish calcschists, which become felspathic and then pass into quartzose schist, which forms the base of the Permian formation. The Carboniferous age of the strata underlying the Permian, and consequently the Permian age of the besimaudite zone itself, was definitely established by fossils found in the Negrone Valley near Viozène, on the southern flank of Montgioie, by Zaccagna, and determined by Professor Portis of Pisa. Soon afterwards this discovery was confirmed independently by Squinabol and by Mazzuoli, both of whom found indubitably Upper Carboniferous fossils in the Bormida valleys already mentioned, where the Carboniferous strata are, moreover, anthracitic.[2]

The distinguishing feature of the besimaudite zone, like that of the equivalent schists of the Apuan Alps, is its gneissiform character, but it also comprises, in upward progression, a variety of associated rocks. Thus, from a granular quartzose schist it passes into greenish-grey compact rock of porphyritic texture with large elongated felspar crystals up to 2 centimetres in length. Again it passes into

[1] "Fossili Paleozoici Alpi Marittime": Atti R. Acad. Lincei, 1877.

[2] A. Portis, Boll. R. Com. Geol., vol. xviii, p. 417, 1887; L. Mazzuoli, ibid., p. 6; S. Squinabol, Giornale Scient. Genova, Fascic. Giugno, 1887. The survey of the Ligurian Alps eastward from the Montgioie range, surveyed by Zaccagna, was carried out concordantly by Mazzuoli and Issel, Boll. R. Com. Geol., 1884 et seq.

The Permian Formation in the Maritime Alps.

FIG. 1.—Sketch-plan. Scale 1 : 1,000,000.

M = Miocene.	P = Permian.
Eo = Eocene.	C = Carboniferous.
L = Lias.	CS = Calc-schist } Archæan.
T = Trias.	G = Gneiss }

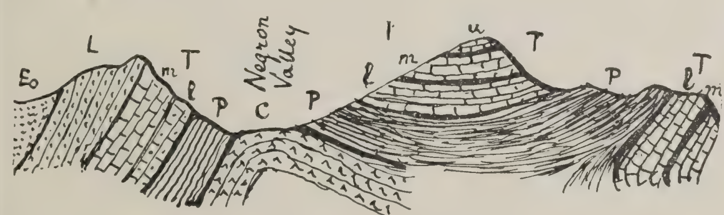


FIG. 2.—Section of Montgioie (2,631 m.), S. to N. Scale 1 : 1,000,000.
T, l, m, u = Lower, Middle, and Upper Trias.

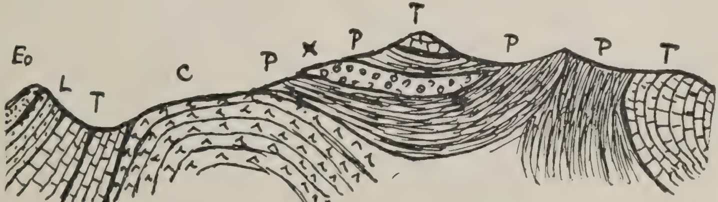


FIG. 3.—Section of Cime de Rocchetta (2,476 m.), S. to N.
× = porphyritic mass.

D. R. P. del.

nodulous gneissiform schist without felspar, or again into sericitic schist, and in places also assumes a granitoid structure, notably above Savona. There are also hornblende-bearing intercalations, simulating the aspect of pietre verdi. In Monte Rocchetta occurs a large mass of reddish porphyritic quartzose rock with white mica crystals, which Zaccagna regards as intrusive porphyry, and which also occurs in Monte Abisso, close to the Col di Tenda Pass; but I am disposed to regard both these masses, which, moreover, lie in a zone, rather as Upper Permian, very similar to the red verrucano or sernifite of the Glarus Alps, a clastic rock which often has all the appearance of porphyry.

The besimaudite zone is directly and conformably overlain by, and graduates into, a coarse conglomerate with white and reddish pebbles in a greenish, talcose matrix. This conglomerate or "anagenite" is of considerable depth in the Montgioie range, and also occurs sparsely in the same position in the Apuan Alps. It represents the Upper Permian or Verrucano formation, and marks a transition from the latter to the Lower Trias. In my opinion the porphyritic masses of Monte Rocchetta and Abisso already mentioned form part of it. It graduates, in its turn, into the conformably overlying Triassic series of quartzite, grey subcrystalline limestone, and calcareous schists, and these are overlain by banks of blackish, brecciform, marmiferous limestone with white calcite crystals, which is quarried near Villanova, at the northern base of the range, and is conspicuous in the columns and ornamental architecture of the churches and palaces of Turin. The Triassic series, about 400 metres in thickness, crowns Montgioie and most of the other principal mountains of the range, on the southern base of which occur also some Liassic and Cretaceous outcrops, followed by a large area of Eocene lime- and sandstone, while on the north it is bordered by an equally extensive area of Miocene marl and molasse.

Thus the stratigraphical sequence of the range, illustrated in the two typical parallel cross-sections of Montgioie and Rocchetta (p. 13, Figs. 2 and 3), exhibits a close analogy to that of the Apuan Alps from the Permian formation upwards. In the Montgioie range the flexures are inclined to the west, where the strata abut unconformably against the gneiss and granite massif of Mercantour; in both the Montgioie and the Apuan range there is considerable folding, but no faulting or unconformity, and their uniformity of age, sequence, and general lithological character is abundantly demonstrated.

III. The Permian in the Western Alps.

From the Montgioie range the Permian formation extends in a westerly direction to the Cottian Alps, and thence continues N. and N.N.E. to the Grajan Alps and the base of Mont Blanc. As the limits of this paper do not admit of a detailed description of the

different localities, suffice it to indicate briefly the alignment of this extension of the Permian zone.

1. *In Dauphiné.* From near Boves at the north-western extremity of the Montgioie range, the Permian, skirting the Monte Viso massif on the right, and that of Mercantour on the left, crosses the Stura Valley, and from here forms an uninterrupted zone about 60 kilometres in length and 2 to 5 kilometres wide to the Ubbaye Valley and Mont Chambeyron (3,388 metres altitude) on the Italo-French frontier. Thence it reappears further north on the south-eastern side of Briançon, near Mont Genèvre, and, skirting the frontier, continues for about 15 kilometres to Mont Chaberton (3,135 metres), this zone being about 2 kilometres in width.[1]

2. *In Savoy.* The next outcrop occurs about 20 kilometres north of the last point, near Modane, below the northern end of the Mont Cenis tunnel, in the Arc Valley, at an altitude of about 1,000 metres, whence it extends in a belt 5 kilometres in average width to St. Bon, Bozel, and Champagny in the Doron Valley east of Moutiers.[2]

It then reappears—

3. *In Northern Piedmont* above Courmayeur, at the foot of Mont Blanc, in the two well-known mountains Chétif and La Saxe (2,343 and 2,358 metres), separated by the Dora Baltea, and again, some 5 kilometres lower down the Dora Valley, in the Pian d'Arp, an eminence near Pré St. Didier.

Throughout this more or less continuous belt from the Maritime Alps to Mont Blanc the Permian exhibits the besimaudite and verrucano characteristics already described, and runs parallel with, and in normal sequence between, the Carboniferous and the Triassic series, so much so that the three zones, with the addition of a narrow Jurassic zone, all bifurcating at Col de Bonhomme, the south-western spur of Mont Blanc, form a belt, more or less interrupted by denudation, round that massif.

[1] The Mont Genèvre group and Mont Chaberton have been dealt with at length in the interesting papers respectively by Cole and Gregory, Q.J.G.S., 1890, p. 305 et seq., and by Davies and Gregory, ibid., 1894, p. 307 et seq.

[2] Near Moutiers are the two geologically famous localities of Petit Cœur and Mont Jovet in the Tarantaise district of the Isère Valley. Near Petit Cœur, about 6 kilometres north of Moutiers, the long-debated phenomenon of a Carboniferous fossiliferous stratum being wedged between two strata of Jurassic fossiliferous limestone was interpreted, among others by Lory, as due to a fault, whereas Zaccagna explained the Carboniferous strip more rationally as the remnant or denuded extremity of a synclinal fold, the other end of which appears in a somewhat larger outcrop at Hautecour, some 6 kilometres east of Moutiers. In Mont Jovet (2,303 metres), on the other hand, the puzzling feature was its being capped by a considerable mass of calc-schist with *pietre verdi* or *vert des Alpes* intercalations, surrounded by a Triassic belt. The former outcrop was regarded by Bertrand as Liassic, while Professor Lory included it in his Triassic metamorphosed *schistes lustrés*, and lastly, Zaccagna recognized it as *schistes lustrés* but of Archæan age, the *pietre verdi* intercalations being conclusive evidence by analogy with Mont Genèvre, Susa, etc. Professor Gregory (Q.J.G.S., 1896, pp. 1–16) concludes in favour of the pre-Carboniferous age of the Mont Jovet schists, but the French Geological Survey definitely adopted Bertrand's view.

Of the Permian outcrops, those of Modane and Courmayeur are of special interest : (1) that of Modane, because Lory and other French geologists included it in their great zone of crystalline metamorphosed Triassic schists, whereas its interposition between Carboniferous and Triassic—both fossiliferous—strata clearly proves its Permian age ; and (2) that of Courmayeur, because Chétif and La Saxe were regarded as granitic spurs of the Mont Blanc massif,[1] whereas Zaccagna recognized them as the northern extremity of a Permian synclinal fold, which is conformably overlain by the Triassic series, and whose southern extremity is the outcrop of Pian d'Arp near St. Didier, already mentioned. It appears again in Mont Mary near Aosta, some 20 kilometres down the Dora Valley.

In Savoy the Permian zone from the Arc Valley at Modane to the Doron Valley south-east of Moutiers has more recently been considerably enlarged by Termier, more especially in the Vanoise region and in the Doron Valley itself.[2] In Dauphiné the crystalline schists of Mont Genèvre near Briançon have also been assigned to the Permian, whereas this formation only skirts the western base of that group, and is overlain by dark, indubitably Triassic limestone corresponding to the grezzoni of the Apuan Alps, while the crystalline schists with diabasic and serpentinous intercalations are classed as Triassic–Liassic *schistes lustrés*.

IV. The Permian in relation to Archæan and Mesozoic Schists.

Intimately connected with the stratigraphical position of the Permian is the demarcation of the Archæan and Mesozoic schists. As is well known, both Elie de Beaumont in the French map (1860) and Sismonda in the Italian map (1862) of the Western Alps divided the crystalline rocks into two great zones—a lower one, comprising indiscriminately the Archæan gneiss, and the Palæozoic and Mesozoic series, as the " metamorphosed Jurassic area " ; and an upper one, embracing the Archæan granite and all the pietre verdi rocks, as intrusive and post-Jurassic. The later maps of Lory and Favre of the French, and of Gastaldi of the Italian side, to some extent disentangled that strange confusion ; Lory and Favre by assigning the gneiss, granite, and the " vert des Alpes " to the Archæan and all the mica- and calc-schists indiscriminately to the Trias as " schistes lustrés ", while Gastaldi separated all the pietre verdi rocks into a zone *per se* as overlying the primitive gneiss and granite zone, and labelled it and the mica- and calc-schists as crystalline rocks, more recent, but pre-Palæozoic. The Permian did not figure in any of those maps.

[1] The Val Veni depression between these two mountains and the granite massif of Mont Blanc is filled with Liassic limestone resting conformably against the Permian of the former but unconformably against the latter.

[2] " Étude sur la constitution géologique du massif de la Vanoise " : Bull. Carte géol. France, vol. ii, No. 20, 1891.

Such was the position in the 'eighties when Zaccagna's revisionary survey showed those more or less arbitrary classifications to be obsolete and untenable. Accordingly he defined the Archæan as composed of two zones—a lower, comprising exclusively the primitive gneiss and granite rocks, and an upper, embracing the mica-schists and the small-grained tabular gneiss ; the calc-schists and crystalline limestone ; and the great masses of pietre verdi as a contemporaneous part.[1] From the Carboniferous formation, till then held to be the only representative of the Palæozoic in the Maritime and Western Alps, he separated the Permian besimaudite and verrucano zone directly overlain by the indubitably Triassic series in which he included Lory's "Lias compacte" or Briançonnais limestone. This definition of the Lower and Upper Archæan, the Upper Palæozoic, and the Lower Mesozoic formations harmonized the two sides of the Western Alps, and was embodied in the new geological map of Italy of 1896, a preliminary sketch of the earlier results in the Maritime and Cottian Alps having been already exhibited at the Berlin Geological Congress of 1885. These were, with variations, adopted by the French Geological Survey and also figured in Vasseur and Carez' geological map of France of the same year. This classification was, however, only two years later superseded by that of Bertrand, Termier, and others on the French side, and by Franchi on the Italian side, the calc-schists or *schistes lustrés* formation with pietre verdi being assigned to the Mesozoic, as explained in paper No. III of this volume.

In so far as the degree of crystallinity, being the effect of metamorphism under pressure and high temperature, is a test of age, the calc-schists differ from the Permian mica- and gneissiform schists as much as do the latter from the Triassic schists of the Apuan Alps. The presence of eruptive rocks, whether primary or altered, both in the Piedmontese calc-schists and in the underlying mica-schists is, of course, no absolute criterion of age, but the enormous pietre verdi masses of Monte Viso, of the Dora Riparia and Lanzo Valleys, and of Val d'Aosta are, by alternation, graduation, and lenticular intercalations, or again, as eruptive dykes, so intimately associated with the two sedimentary horizons that they constitute integral and contemporaneous parts of these formations respectively and point to two separate and corresponding periods of submarine eruption.[2]

[1] The small-grained tabular gneiss (*gneiss minuto tabulare*) is extensively quarried in the Susa, Chisone, and Pellice Valleys for building purposes in Turin.

[2] In Piedmont alone the crystalline schists, lying between the Mercantour massif in the south and Monte Rosa in the north, cover an area of 200 by 30 kilometres, or roughly 2,400 square miles, of which the three principal *pietre verdi* masses represent about one-fifth. These masses are all composed of basic rocks, more especially of diorite, diabase, gabbro, serpentinous and hornblendic rocks. The white marble of Susa belongs to the calc-schist

V. Conclusion.

In the necessarily small sketch-plan (p. 11, Fig. 1) I have traced the Permian zone from the Ligurian Alps near Savona through Southern Piedmont, Dauphiné, and Savoy to Mont Blanc, a distance of 250 kilometres. It is seen that the curved alignment of that zone, which would equally apply to the concomitant Carboniferous and Triassic zones, runs, in the main, between and parallel to the two great primitive gneiss and granite belts indicated by dotted lines, the outer belt comprising the Mont Blanc massif and the Pelvoux group in Dauphiné, while the inner, more continuous one extends from Monte Rosa to Gran Paradiso and Mercantour in Southern Piedmont.[1] A third, smaller, but continuous inner belt may be said to lie between the Dora Riparia and the Maïra Valleys, with the Monte Viso group on its western flank.

The surface-level of the Permian zone varies between 2,000 and 1,000 metres altitude, the highest being at Montgioie and Chétif (Courmayeur) and the lowest near Modane and in the Doron Valley, while the parallel primitive gneiss zones vary in altitude between 4,000 and 3,000 metres. It is therefore obvious that the Permian and concomitant zones must have been deposited in a longitudinal trough at a time when the older gneiss groups had already experienced a first partial raising, followed by a long period of erosion. The marked unconformity at the points of contact between these formations warrants the same inference of a long intervening period of erosion. A further uprise, which also affected the secondary formations, appears, on similar grounds of unconformable superposition, to have taken place in post-Liassic times,[2] and a third occurred in Miocene times, which last-named movement, proceeding, like the preceding ones, mainly in a radial sense from the south-east, viz. from the Mediterranean, probably imparted to the Maritime and the Western Alps, as also to the Ligurian and Apuan ranges, their present general alignment and configuration.

The initial emergence of the Montgioie and Apuan ranges as ellipsoidal groups probably occurred before that of the Apennines; but it is during the third and last great movement that the final

horizon, and, like the marble of the Apuan Alps, attests the process of the deposition of coarse calcareous material being followed by that of gradually finer to very fine material purified by solution and precipitation. The majestic triumphal arch at Susa shows that the marble of that locality, as that of Carrara, was quarried already by the Romans. Similar saccharoidal limestone intercalations are also worked in the Pellice, Upper Po, and Varaita Valleys.

[1] C. Diener outlines a similar series of belts in his "Gebirgsbau der Westalpen", 1891, but embraces in his generalizations the entire chain of the Alps.

[2] Of this post-Liassic uprise, followed by a period of erosion, evidence is afforded by a general and marked discordance between the strata of the Upper Lias and the Tithonian, and, again, between the Neocomian and the Senonian both in the Western and in the Apuan Alps.

uprise of the Permian schists, already more or less subjected to metamorphism and overlain by the younger formations, must have taken place in the Apuan Alps as the nucleus of that range, and as its average surface-level of about 1,500 metres above the sea is the same as that of the analogous zone in the Maritime and Western Alps, it follows that the Permian formation in all the three ranges must have been raised to its present level simultaneously in Miocene times.

III.

The "Pietre Verdi" Groups of the Piedmontese Alps.

IN the preceding paper on the Permian Formation in the Alps of Piedmont, Dauphiné, and Savoy,[1] I referred incidentally to the large masses of pietre verdi or greenstones which constitute perhaps the most striking geological feature of the extensive areas covered by the crystalline rocks of the Piedmontese Alps in a crescent-shaped curve about 200 miles in length from the Maritime range to Monte Viso, Gran Paradiso, and Monte Rosa. In the present paper I propose to deal more fully, although necessarily within narrow limits, with these pietre verdi which, owing alike to their extraordinary development, variety, and complexity, to their intimate association with each other and with the crystalline sedimentary rocks, and to their intricate composition and origin, have for the last fifty years presented most interesting problems and passed through many remarkable phases of interpretation. As a necessary preliminary to a description of the different areas, it will be convenient to briefly consider the most recent classification of the crystalline formations of the Piedmontese Alps generally, and of the pietre verdi rocks in particular.

I. Classification of the Crystalline Formations.

In a short paragraph of the previous paper already quoted I outlined the sequence of the crystalline rocks of the Piedmontese Alps as evolved by Zaccagna in his memoirs of 1887 and 1892.[2] In this classification he retained Gastaldi's two principal pre-Palæozoic zones or horizons,[3] but with this essential difference, that for Gastaldi's upper or so-called pietre verdi zone he substituted the mica-and-calc schist zone with pietre verdi as associated rocks, the latter being, in point of superficial area, a subordinate, the former the predominant part of the whole formation. Zaccagna's two Archæan zones thus comprised: (1) a lower zone, restricted exclusively to primitive gneiss and granite without pietre verdi; and (2) an upper zone, graduating, in ascending order, from minute and tabular gneiss to mica-schists and calc-schists, each group with crystalline limestone and pietre verdi. This classification received the imprimatur of the

[1] Geol. Mag., January, 1916, p. 7; ibid., p. 15.

[2] D. Zaccagna, "Studi geol. sulle Alpi Occid.": Boll. R. Com. geol. d'It., 1887, p. 346 et seq. "Riassunto di Osserv. sul Versante Occid. Alpi Graje": ibid., 1892, p. 175 et seq.

[3] B. Gastaldi, "Studi geol. sulle Alpi Occid.": Mem. R. Com. geol. d'It., 1871, vol. i, p. 3 et seq. "Spaccato geol. lungo le valli sup. Po e Varaita": Boll. R. Com. geol., 1876, p. 104 et seq.

Italian Geological Survey under its eminent Director, the late Comm. F. Giordano,[1] and was also accepted by the French Survey, by Bertrand, Termier, and other French geologists. It seemed to derive additional force from the more intense metamorphism and crystallinity, progressing from west to east, of the rocks on the Piedmontese as compared with those on the French side of the Western Alps; and this, together with the fact that until then, about 1890, no determinable fossils had been found even in the uppermost calc-schist horizon, seemed to warrant the entire crystalline series of Piedmont being *at that time* classed as of pre-Carboniferous, and, in the absence of the Lower Palæozoic, of Archæan age.

But in 1894 Bertrand returned to his former view of the Mesozoic age of the schistes lustrés which, in opposition to the late Professor Lory's Triassic and to Zaccagna's Archæan views, he and Termier had already pronounced Liassic in the well-known case of Mont Jovet in Tarantaise (Isère Valley).[2] In his *Études dans les Alpes Françaises* [3] Bertrand maintained the Liassic age of the calc-schists not only on the French but also on the Italian side, on the ground that Triassic masses frequently underlie the calc-schists. Even before the publication of that work, Professor Parona, of Turin, had discovered Radiolaria in the silico-calcareous mass associated with the calc-schists pietre verdi (serpentine) of Mont Cruzeau, near Cesana,[4] a discovery followed a few years later by other evidence of characteristic Liassic, Rhætian, and Triassic fossils in the dolomitic and calcareous masses which, in the lower as well as in the upper valleys of both Southern and Northern Piedmont, occur at varying levels of the calc-schist horizon, either resting on, or intercalated between, or in some cases at the base of, the crystalline calc-schist strata. These discoveries were due chiefly to the untiring industry and perseverance of Franchi, who, in two important memoirs of 1898 and 1904,[5] claimed to have established the Mesozoic, and more

[1] Boll. R. Com. geol., 1887, pp. 342–5.

[2] P. Termier, "Sur le Permien du massif de la Vanoise": Bull. Soc. géol. France, vol. xxi, p. 124 et seq., 1893.

[3] M. Bertrand, Bull. Soc. géol. France, vol. xxii, p. 69 et seq., 1894.

[4] C. F. Parona, "Sugli Scisti silicei a radiolarie di Cesana presso il Monginevra": Atti R. Acc. Sc. Torino, vol. xxvii, 17. Gennajo, 1892; also noticed in Davies and Gregory's paper on "The Geology of Mont Chaberton": Q.J.G.S., 1894, p. 303 et seq.

[5] S. Franchi, "Sull'età mesozoica della zona delle pietre verdi nelle Alpi Occidentali": Boll. R. Com. geol., 1898, pp. 173, 325 et seq. "Ancora sull'età mesozoica, etc.": ibid., 1904, p. 125 et seq. Franchi, Novarese, and Stella were in charge of the detailed survey of the Piedmontese Alps for the new 1 : 100,000 map in conjunction with Mattirolo, who supported Zaccagna's interpretation. Franchi published in Boll. R. Com. geol., 1909, p. 252, a forty-page reference of the literature on the crystalline schists from Gastaldi (1871) downwards.

The principal localities which yielded Triassic and Liassic fossils in the calcareous and dolomitic masses of the calc-schist horizon are the Grana, Vermenagna, Narbone, Maira, Elva, and Varaita Valleys in S. Piedmont; Chianoc and Forrest in the lower, and Rocca d'Ambin, Gad d'Oulx, and Bardonecchia in

especially the predominantly Liassic, age of the calc-schist formation, including in the same the pietre verdi as associated rocks. He thus assimilated the age of that formation and that of the schistes lustrés in accordance with Bertrand's views, with which he is thoroughly imbued and which, since Bertrand's death, have been upheld and even carried considerably further by Termier.

Franchi's memoirs and his evolution from the Archæan to the Mesozoic led to a controversy as interesting as it was vigorous and protracted, between Zaccagna and himself, not as to the facts, which were not in dispute, but as to the interpretation of the same. To Franchi's contention Zaccagna [1] opposed, on stratigraphical grounds, his own explanation that the fossiliferous calcareous and dolomitic deposits occur in eroded gaps and as squeezed wedges (*pizzicature*) in the crystalline calc-schists, in which they were infolded by dynamic action, in certain cases by displacements due to local overthrusts, and that as such they are quite distinct from the true calc-schists, whose pre-Palæozoic age he therefore strenuously reaffirmed.[2] In the result Professor Taramelli of Pavia, and Professor Parona, of Turin, as referees appointed by the Geological Survey, recommended, in their reasoned report of 1911,[3] that in the new large-scale map 1 : 100,000 of the Piedmontese Alps, Franchi's interpretation, as being more convincing and up to date, should be adopted, their conclusion being, therefore, in favour of the Mesozoic age of the upper crystalline or calc-schist formation.

Thus, in the most recent Italian Geological Survey map 1 : 100,000, as also in the one of 1 : 400,000 of 1904, the Piedmontese calc-schist formation has been rejuvenated as equivalent to, and contemporaneous with, the schistes lustrés of the French, the Bündner-

the upper Susa Valley; Villeneuve in the upper Aosta Valley, and the Col du Petit St. Bernard, all in Northern Piedmont. The fossils, most of which were determined by Professor di Stefano and Professor Canavari, include, among others, Radiolaria, Belemnites, *Arietites*, Crinoids, *Encrinus, Pleurotomaria, Avicula, Corallari, Gyropellæ, Pentacrinus, Phylloceras*, etc.

[1] D. Zaccagna, "Osservazioni sugli ultimi lavori intorno alle Alpi Occidentali": Boll. Com. geol., 1901, pp. 4, 129; 1902, p. 149; 1903, p. 297.

[2] Zaccagna's contention tallies in the main with Professor Bonney's as to the occurrence of Jurassic and Triassic wedges in the crystalline schists of the Alps. "Mesozoic Rocks and Crystalline Schists in the Lepontine Alps": Q.J.G.S., 1894, p. 285; also ibid., p. 277. Baretti (Studi Gran Paradiso, etc., 1876–7), following Gastaldi's views, also considered the French calc-schists the upper and the Piedmontese calc-schists as the lower crystalline formation.

[3] T. Taramelli and C. F. Parona, "Relazione sull'età de assegnarsi alla zona delle pietre verdi nella Carta geol. delle Alpi Occidentali": Boll. R. Com. geol., 1911, pp. x–xxiv. The controversy between Franchi and Zaccagna turned more especially on the great calc-schist area extending from the Gesso Valley in Southern Piedmont parallel to the Franco-Italian frontier to the Susa and Aosta Valleys towards Monte Rosa. The smaller, isolated area of Courmayeur, running parallel to Mont Blanc, was recognized as Liassic and Triassic, and was, therefore, not in dispute.

schiefer of the Swiss, and the Schieferhülle of the Austrian Alps, all of uniformly recognized Mesozoic age. It figures, therefore, as the Liassic–Triassic crystalline " Piedmontese " facies, with two subordinate facies—the " mixed " and the " ordinary " Trias. This rejuvenation, which is practically a reversion, *mutatis mutandis*, to Sismonda's " metamorphosed Jurassic schists " of the early 'sixties, entailed a similar stratigraphical process as regards the mica-schists and the minute, tabular, and graphitic gneisses which, accordingly, are now assigned to the Permo-Carboniferous, corresponding to Bertrand's and Termier's " série cristallophyllienne permo-carbonifère ". The only formation left to the Pre-Carboniferous is therefore that of the primitive gneiss belt of the Mercantour, Maira-Dora, and Gran Paradiso massifs, which formation constitutes the practically undisturbed substratum of all the later series.[1]

This primitive gneiss, often of granitoid and porphyroid structure with large felspar crystals up to 8 centimetres in length, differs lithologically from the more recent minute and tabular gneiss, chiefly in that the small-grained elements of the latter are conspicuously rich in quartz and predominantly white mica. As regards the calc-schists, they are composed prevalently of calcite, aggregations of quartz in minute granules, and with white or greenish mica, the rock being generally of grey and often blackish colour due to a carbonaceous pigment, with numerous minute crystals of pyrite and other metallic minerals. When this typical calc-schist is deficient in calcite or loses it altogether, it assumes an essentially phylladic character ; when, on the other hand, calcite predominates over the other minerals, the calc-schist becomes micaceous crystalline limestone or " calcefiro " ; and when the crystalline limestone is, by contact, impregnated with serpentinous matter, it becomes " ophicalce ", as e.g. the green marble of Susa.

The new classification, besides harmonizing with all the most recent and authoritative interpretations west and north of the Alps, has the further signal advantage of having eliminated Gastaldi's " pietre verdi zone ", which, in his separate and far too comprehensive sense, had become a fruitful source of misconception. As

[1] The official geological map of France, 1 : 1,000,000, published in 1904, which extends to the Italian side as far as the Po Valley, includes in the Permo-Carboniferous not only the minute and tabular gneiss and mica-schists, but also the primitive gneiss belt, for which there is no warrant. Similarly, Termier (" Les schistes cristallins des Alpes occidentales," Comptes Rendus du Congrès géol. Vienne, 1913) embraces in his *série cristallo-phyllienne triassique compréhensive* all the younger formations down to the Eocene inclusive. Both cases are ultra-synthetic, and are not accepted by the Italian Survey.

Professor Gregory's view that the gneisses which he terms *Waldensian* (Q.J.G.S., 1894, p. 232 et seq.) are Pliocene and intrusive runs counter to the accepted interpretation of the coarse-grained gneiss being the primitive, viz. " fundamental ", substratum of the Cottian and Grajan Alps. Professor Gregory's conclusions are traversed also by Novarese, " Rilevamento geol. Valle Germanesca (Alpi Cozie), 1894," Boll. R. Com. geol., 1895, p. 277 et seq., and Franchi, ibid., 1897, p. 13 et seq.

experience has shown, pietre verdi with primitive or secondary elements are not peculiar to any particular horizon, and throughout Italy, as elsewhere, occur in all the formations from the Eocene down to the Palæozoic ; in the Piedmontese Alps, though in a special form, even in the primitive gneiss.

Apart from these considerations, the new classification of the Piedmontese crystalline calc-schists as Mesozoic and the underlying mica-schists as Permo-Carboniferous, corresponding to the analogous crystalline formations of the French Alps, is, in my opinion, fully warranted by the evidence adduced by Franchi and his coadjutors, to which I can bear witness from personal observation, notably in the Dora Riparia (Susa) and the Dora Baltea (Aosta) Valleys, as also in Southern Piedmont in the test cases on which the referees Profs. Parona and Taramelli founded their conclusions. The greater part of that evidence only came to light in the course of the detailed and large-scale survey of the different regions, i.e. after Zaccagna's more general survey, and thus rendered the latter's Archæan interpretation untenable. An additional important reason in favour of the more recent age of the calc-schist formation is, in my view, that much of its area in Southern Piedmont west of the Monte Viso group between the Stura di Cuneo and Chisone Valleys, is probably an overthrust from the Dauphiné side of the Alps, whereas the older mica-schist horizon both of Southern and Northern Piedmont, as also the calc-schists of the latter region, are essentially formations in situ. As regards the pietre verdi masses associated with the successive sedimentary formations respectively, their submarine eruptions probably took place during and as the effect of great earth movements, each series of these eruptive rocks thus marking a great period of folding due to the contraction of the earth's crust.

II. Classification of the Pietre Verdi.

In order to avoid tedious repetition, it will be convenient to specify briefly the leading varieties of the pietre verdi, some of which have characteristics peculiar to the Piedmontese Alps. Gastaldi, with his wonderful intuition and perspicacity, laid down certain broad lithological distinctions which, in the main, are still correct. They were used by his immediate contemporary followers Strüver and Baretti, and after them by Bucca,[1] in their excellent and diffuse macroscopic and microscopic investigations, and until recently also by Zaccagna and Mattirolo ; but the results of the detailed survey and the consequent extension of microscopic work, notably by Franchi, Novarese, and Stella, have led to revised

[1] G. Strüver, "Cenni sui graniti massicci delle Alpi Piedmontesi e sui minerali delle valli di Lanzo" : Mem. descr. Carta geol. d'Italia, 1871, p. 37 et seq. M. Baretti, "Studi geol. sul gruppo del Gran Paradiso" : Mem. Acc. Lincei Torino, vol. i, p. 197 et seq., 1876–7. L. Bucca, "Appunti petrogr. sul gruppo del Gran Paradiso" : Boll. R. Com. geol., 1886, p. 449 et seq.

and more precise definitions, more especially in reference to the amphibolic and prasinitic series which Gastaldi included indiscriminately in his " amphibolic " or " magnesian schist zone ".

On the rational ground that not amphibole, i.e. hornblende, but triclinic felspar is the most prevalent constituent of pietre verdi, the revised nomenclature divides all the basic rocks of the Piedmontese Alps into three groups on a felspathic basis, viz. rocks in which felspar, as a constituent element, is essential, subordinate, or absent. In the following table I have enumerated only the principal, most diffused rocks, without their schists, their infinite graduations, and their often overlapping varieties and combinations.[1]

Pietre Verdi Rocks.

I. *Rocks with primitive elements.*

Felspar	(1) *Essential.*	Diorite, diabase, porphyrite, gabbro, and their varieties.
	(2) *Subordinate.*	Felspathic lherzolite, felspathic hornblendite.
	(3) *Absent.*	Lherzolite and peridotite, hornblendite.

II. *Rocks with secondary elements.*

Felspar	(1) *Essential.*	(*a*) Prasinite group: with a dominant non-felspathic element, viz. chloritic, amphibolic (actinolite and glaucophane), or epidotic prasinite, and varieties.
		(*b*) Euphotide and its varieties.
	(2) *Subordinate.*	(*a*) Amphibolite group: felspathic and epidotic amphibolite with frequent glaucophane.
		(*b*) Epidotites and zoisitites, felspathic.
	(3) *Absent.*	(*a*) Amphibolite group: epidotic and garnetiferous amphibolite with dominant glaucophane, eclogite.
		(*b*) Epidotite, zoisitite.
		(*c*) Serpentine, serpentinous, chloritic, and talcose schist.

It will be seen that the old generic group of amphibolites or hornblendic rocks is separated into amphibolites proper and prasinites, the last-named designation having been adopted from Kalkowsky and Zirkel as basic rocks or " Grüneschiefer " of a felspathic basis with chlorite, hornblende (the bright-green actinolite or the bluish-green or violet fibrous glaucophane) and epidote, one of these being dominant as a non-felspathic element. The amphibolites, largely derived from diorite and composed of albite, epidote, and dominant amphibole, are mostly compact, passing to schistose, although the hardest, massive amphibolite, viz. " hornblendite " or " Hornblendefels ", is, in large masses, comparatively rare in the Piedmontese Alps. The prasinites, on the other hand, are on the whole less compact and more often schistose, and in the main, like the amphibolites, altered, transformed, or metamorphosed from

[1] The table is founded on the nomenclature worked out by Novarese and Franchi, Boll. R. Com. geol., 1895, p. 164 et seq. and p. 181 et seq.; but I have arranged it somewhat differently so as to group the rocks with primitive and those with secondary elements separately and more prominently.

massive eruptive rocks. They often contain, as an accessory mineral, white mica, but rarely biotite, and include, as a largely diffused variety, the chloritic rock " ovardite ", first recognized and so named by Strüver [1] from Torre d'Ovarda, a ridge in one of the three Stura di Lanzo valleys. It is composed of epidote, microscopic amphibole, and predominant chlorite in a plagioclasic groundmass. Amphibolic schist, the equivalent of " Hornblendeschiefer ", is intermediate between amphibolites proper and prasinites.[2]

A further distinction made is that between gabbro and euphotide [3] in the sense that gabbro is restricted to the primary felspathic rock with its elements unaltered, while in euphotide the triclinic felspar is already altered to saussurite and the diallage to smaragdite—the latter being, like epidote and the amphibole varieties, a largely diffused mineral in the Piedmontese Alps.

Again, massive serpentine, as the direct product of altered lherzolite and peridotite, is distinct from serpentine schist, which is a further stage of alteration, and still more from serpentinous schist, which, occurring frequently as intermediate between crystalline schists or, again, between crystalline limestone and pietre verdi, is the product of chloritic decomposition of the latter. As such it may, by the abstraction of magnesia, be derived from any of the basic rocks with altered elements, notably from euphotide, amphibolite, and prasinite, or their schists, although the prototypes of these rocks—gabbro, diorite, and diabase—have, apparently, no identity of origin or affinity with serpentine proper. So-called serpentinous schist is therefore *pseudo*-serpentine, and represents, together with chloritic and talcose schist, probably the last stage of alteration and metamorphism, not only of serpentine but of some of the other pietre verdi series.

The rocks with altered elements often assume a laminated, gneissiform structure, and exhibit a marked affinity with gneiss or, again, with mica-schists, and even with calc-schists. Thus minute gneiss becomes amphibolic, prasinitic, or epidotic ; mica-schist becomes epidotic and even more frequently glaucophanic when in association with the blue glaucophane or gastaldite variety,[4] while ovardite,

[1] Strüver, Una Salita alle Torre d'Ovarda, Torino, 1873, and Bucca, loc. cit., 1886, p. 453.

[2] The felspar-actinolitic rock noticed by Professor Bonney near Fenestrelle in the Chisone Valley (" Two Traverses of the Crystalline Rocks of the Alps ": Q.J.G.S., 1889, p. 80 et seq.) is an amphibolic prasinite, viz. ovardite, while the schist with glaucophane, the epidiorite, and the dark-green porphyrite mentioned by Professor Gregory in his " Waldensian Gneisses ", loc. cit., come under the category of prasinites (ovardites) and amphibolites.

[3] The term euphotide refers to the younger and altered gabbric rocks. The Tuscan term gabbro is arbitrarily derived from a hill and village near Leghorn. *Vide* Part II, p. 124.

[4] Gastaldite is the name given by Strüver to a special blue variety of glaucophane, much richer in alumina than the ordinary violet or greenish-blue glaucophane or secondary hornblende.

when very rich in chlorite and taking up mica, quartz, and calcite, passes into prasinitic calc-schist and phyllite.

The massive eruptive rocks with primitive elements—diorite, diabase, gabbro, pyroxenic-biotitic porphyrite (Gastaldi's melaphyre) and the enormous peridotic masses—occur more especially in the gneiss and mica-schist area of Northern Piedmont, that is, in the so-called dioritic belt or "Ivrea zone" which extends from the eastern spurs of the valleys converging near Avigliana, west of Turin, to the Lanzo spurs, and thence north-east to Ivrea, Biella, and the Sesia valley, and beyond the latter to the Strona valley near Lake Orta. The same "Ivrea zone" also extends into the Aosta valley and the valleys descending from Monte Rosa. The amphibolic, prasinitic, euphotidic, and serpentinous series with secondary elements, on the other hand, predominate in the calc-schist and mica-schist area from the upper Lanzo valleys south to Monte Viso and the Maritime Alps, and extend into the Permian and Triassic formations of the latter. The considerable euphotidic and diabasic masses of the Grana and Maira valleys south of Monte Viso are all more or less profoundly metamorphosed to epidotic (zoisitic), amphibolic, and prasinitic rocks,[1] and therefore do not belong to the category of eruptive rocks with primitive elements.

The constant and intimate association of the pietre verdi not only with each other but with the stratified mica- and calc-schists led Gastaldi, as previously stated, to regard all those rocks, with the only exception of the primary eruptive rocks of the Ivrea belt, indiscriminately but erroneously as metamorphosed sedimentary.[2] The pietre verdi both in their primary and secondary forms are now recognized to be in the main of eruptive origin. At the same time the constant alternations, amounting to interstratification, of the pietre verdi with each other; their stratiform, if not actually stratified, character in relation to the sedimentary rocks, and their frequent wedges and lenticular intercalations in the latter—all these phenomena on a large scale still present an intricate problem to which I shall refer in the descriptive sequel to the present paper.[3] The problem of the age of the pietre verdi in relation to the older rocks is, of course, rendered more difficult by the obliteration in the latter of organic remains through the ceaseless action of metamorphism past and present, or, in the words of Gastaldi: "while Nature gives us on this Earth myriads of living species, she with relentless hand destroys all trace of former life below."

[1] S. Franchi, "Alcune metamorfosi di eufotidi e diabasi Alpi Occid.": Boll. R. Com. geol., 1895, p. 181 et seq.

[2] Hence his well-known dictum: "In the Piedmontese Alps plutonism is a myth." It was not, however, adopted even by his immediate followers, Strüver, Baretti, Bucca, and others.

[3] Professor Bonney has described an instructive case of the conversion of greenstone into crystalline schist on a small scale in the Bernina region, Q.J.G.S., 1894, p. 279 et seq.

IV.

The Crystalline Formations of the Piedmontese Alps.

Southern, Western, and Northern Piedmont.

Introductory.

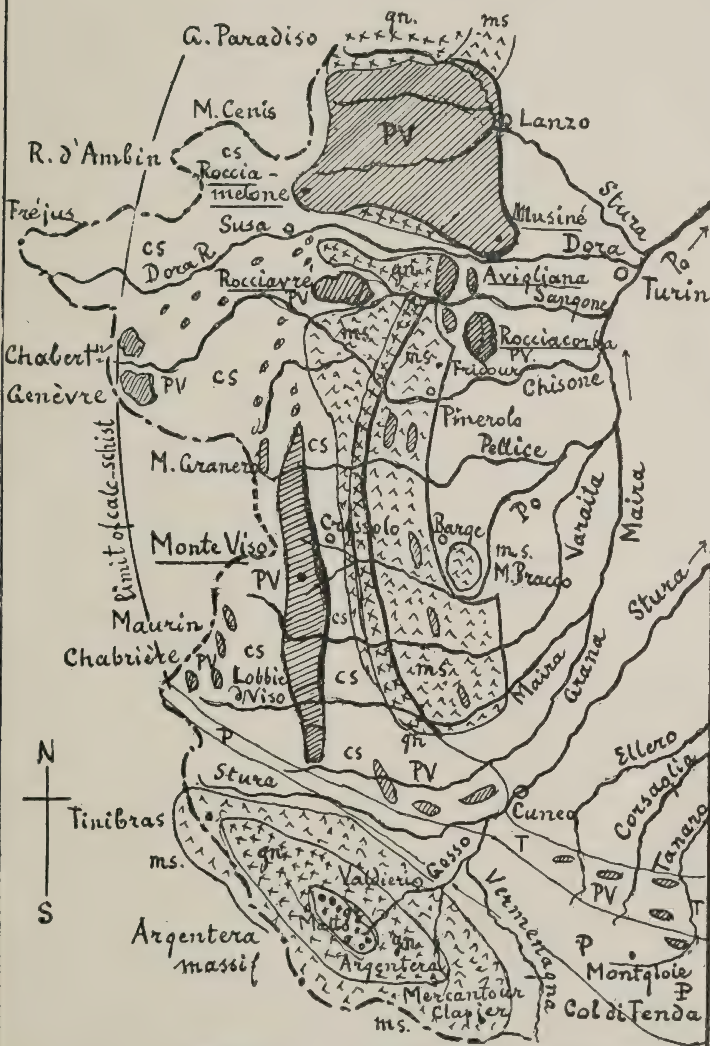
In continuation of the preceding paper (No. III), which, as a preliminary to the present one, outlined the new classification of the crystalline rock formations and the nomenclature of the pietre verdi of the Piedmontese Alps, I now propose to briefly describe the principal pietre verdi areas with which I became familiar during a long stay on repeated occasions in Turin. This city, apart from its rich collections of the rocks and minerals of the Piedmontese Alps, is a most central and convenient starting-point for examining the different valleys debouching into the plain of the Po from the magnificent crescent formed by the Maritime, Cottian, Grajan, and Pennine Alps, which, as seen from Turin, afford by far the most extensive and fascinating Alpine panorama in Italy.

The principal pietre verdi areas lie more especially along or near the inner belt or concave eastern edge of the Alpine crescent, and include, among others, the following mountains and valleys which will be referred to in this and a subsequent paper, and all of which form part of the watershed of the Po :—

Range.	*Mountain.*	*Altitude.*	*Valleys.*
		m.	
Maritime	Montgioie	2,836	Bormida, Tanaro, Corsaglia, Ellero, Vermenagna.
,,	Argentera	3,397	Gesso, Stura di Cuneo.
Cottian	Monte Viso	3,843	Grana, Maira, Varaita, Po, Pellice, Germanasca.
,,	Rocciavré	2,778	Chisone, Sangone.
Grajan	Rocciamelone	3,537	Dora Riparia (Susa Valley).
,,	Ciamarella	3,876	Stura di Lanzo : Usseglio, Balme, and Grande Valleys.
,,	Gran Paradiso	4,081	Orco, Soana.
,,	Grivola	3,961	Dora Baltea (Aosta Valley), Cogne, Valsavaranche.
,,	Mte. Emilius	3,559	Dora Baltea, Buthier, Valpelline.
Pennine	Mte. Rosa	4,636	(Ivrea Belt) Chiusella, Dora Baltea, Tourmanche, Gressonay, Cervo, Sesia.

Of the mountains enumerated, the Argentera and Gran Paradiso massifs, with a gneiss nucleus in each case, are the only ones which

Fig. 1, SKETCH-MAP
of Crystalline Rock Areas in Piedmontese Alps
(Southern and Western Piedmont.)



PV = pietre-verdi ; gn = gneiss ; gr = granite ;
ms = mica-schist ; cs = calc-schist ; P = Permian ;
T = Trias.

Scale 1 : 1,100,000. Del. D.R.P.

have preserved their original ellipsoidal, dome-shaped outlines, while most of the others, lying in the calc-schist and pietre verdi areas, are conspicuous pyramids whose precipitous flanks, pre-eminently those of Monte Viso and Grivola, were chiselled probably quite as much by atmospheric as by fluviatile or glacially abrasive action. The eight principal crystalline groups will be dealt with in the present and two subsequent papers as follows :—

I. *Southern Piedmont.* 1. The Maritime Alps group (Montgioie and Argentera). 2. The Monte Viso group.

II. *Western Piedmont.* The Dora Riparia groups : 1. Rocciavré. 2. Rocciamelone. 3. Rocciacorba and Avigliana.

III. *Northern Piedmont.* 1. The Lanzo Valleys and Gran Paradiso groups. 2. The Dora Baltea (Val d'Aosta) groups. 3. The Lanzo, Ivrea, and Val Sesia groups.

I. Southern Piedmont.

1. *The Maritime Alps Group.* (Fig. 1.)

1. *Montgioie Range.*—The pietre verdi area between the Ellero, Corsaglia, Tanaro, and Bormida Valleys, on the north side of the Montgioie range derives special interest from the fact that the deposits occur in the Permian and Triassic crystalline formations, already described in a previous paper,[1] while further east, towards Savona and near Voltri in Liguria, similar masses are intercalated in Triassic schists and further west, along the French frontier, they appear in the calc-schist formation. Proof is thus afforded that the pietre verdi are not confined to any particular horizon, but are associated with both Mesozoic and Palæozoic formations. Some of the pietre verdi masses on the northern slopes of the Montgioie range were already mentioned by Zaccagna [2] ; but their number and extent has more recently been considerably increased by Franchi,[3] who regards all the pietre verdi of the Ligurian, Maritime, and Cottian Alps as links in the same Mesozoic horizon.

The pietre verdi masses between the Ellero, Tanaro, and Bormida Valleys, extending for about 30 kilometres along the lower hills from Villanova to Millesimo, are composed chiefly of lenticular masses of serpentinous, diabasic, and euphotidic rocks, the latter two largely altered to amphibolites and prasinites, all associated with Triassic crystalline and dolomitic limestone, in the Bormida valleys also with Permian schist, as already mentioned. In these, as also in the Lower Trias, occur frequent outcrops of laminated porphyritic rock

[1] "The Permian Formation in Piedmont, Dauphiné, and Savoy" : No. II of this volume.

[2] D. Zaccagna, "Alpi Marittime" : Boll. R. Com. geol., 1889, p. 395 et seq.

[3] S. Franchi, "Zona Pietre Verdi fra l'Ellero e la Bormida, Alpi Marittime" : ibid., 1906, p. 89 et seq.

and masses of amphibolic schist often epidotic and garnetiferous, with abundant glaucophane.[1]

West of the Montgioie range, in the border zone of the Maritime and Cottian Alps, and notably in the upper Grana and Maira Valleys, similar euphotidic and diabasic masses occur in the calc-schist formation, but intensely metamorphosed, the former to epidotic and chloritic prasinites with or without gastaldite (blue secondary hornblende), the latter to felspathic prasinites and amphibolites.[2] These pietre verdi masses bear close analogy to the euphotidic and diabasic, also variolitic masses with overlying serpentine in the calc-schists of Maurin and of the Chabrière Valley, near Pointe de Mary, about 30 kilometres further north-west, as also to those of the Mont Genèvre group another 30 kilometres further north, and to those between the Ripa and Troncéa Valleys about 20 kilometres east of Genèvre. From the occurrence of all these crystalline masses both of eruptive [3] and sedimentary origin on the northern and eastern flank of the Permian horizon, Franchi has rightly concluded that that formation separates the Trias into two distinct zones: an external one on the left, composed of the ordinary, fossiliferous limestone, gypsum and "cargneules" or Briançonnais facies, and an internal zone, the crystalline and semi-crystalline facies composed of the calc-schists and crystalline and dolomitic limestone with pietre verdi.

2. *The Argentera Massif* (Fig. 1).—This massif, also called Mercantour, is an oval-shaped ellipsoidal group of 60 by 25 kilometres in approximate length and width, extending west of Col di Tenda along the French frontier, and bordered on the north by the Stura di Cuneo Valley, which separates the Maritime from the Cottian Alps. The massif includes besides Monte Argentera (3,397 m.) and Monte Matto (3,057 m.) in the centre, some of the highest mountains of the Maritime Alps, e.g. Mercantour (2,775 m.) and Monte Clapier (3,046 m.) at the south-eastern, and Monte Tinibras (3,032 m.) at the north-western end. The access to the central part is by the Gesso Valley from Valdieri, whose well-known hot sulphur springs rise in the upper valley, at 1,346 metres altitude, almost in the centre of the massif. The latter is, like the Dora-Maira and Gran Paradiso

[1] The nomenclature used throughout this paper is that given in the preceding one, No. III.

[2] S. Franchi, "Alcuni Metamofisi di eufotidi e diabasi Alpi Occid.": Boll. R. Com. geol., 1895, p. 181 et seq. The transformation described in this important memoir applies equally to similar phenomena in all the other pietre verdi areas of the Piedmontese Alps. In the massive and schistose amphibolites of the Grana and Maira Valleys, as also in Val Chisone, at Pegli, Liguria, and in the Tuscan archipelago, Franchi found the equivalent of the Californian mineral lawsonite, a secondary pseudomorphic plagioclase corresponding to the formula of hydro-anorthite felspar (Boll. R. Com. geol., 1898, p. 308).

[3] The term "eruptive" is used in this paper in preference to "igneous" as better corresponding to the character of the Piedmontese rocks as submarine expansions.

gneiss massifs, entirely free from pietre verdi on its surface ; even the fringe of pietre verdi which surrounds those massifs is absent on its periphery. Zaccagna attributes this isolation of the Argentera massif to a great fault along the Stura Valley, which latter is, some 20 kilometres north-east of Valdieri, crossed by a succession of pietre verdi outcrops descending from the Maira and Grana Valleys towards Cuneo and S. Dalmazzo, and thence running along the base of the Montgioie range to Villanova and Millesimo.

The Argentera massif consists, in the main, of three crystalline formations : a nucleus of primitive, glandular, large-grained, granitoid, and eye-gneiss ; [1] a large area, about 12 by 10 kilometres, of granite intrusive in the gneiss nucleus ; and a surrounding belt of great masses of small-grained gneiss and mica-schist. The primitive gneiss, and to a much lesser extent also the intrusive granite, is traversed in all directions by countless thin veins of acid rocks, chiefly microgranite, aplite, quartziferous and hornblendic porphyrite, while the outer gneiss contains intercalated masses of both augitic and hornblendic diorite and of compact serpentine. These rocks, being here intimately associated with gneiss, are not pietre verdi with secondary elements ; but they show that the prototypes of the latter are not wanting even in the more ancient crystalline series.

Professor Sacco regards the position of the gneiss and granite of the Argentera massif as reversed, viz. the granite not as intrusive, but as constituting the nucleus of the massif, enveloped by an enormous mass of gneiss intensely metamorphosed and of Permo-Carboniferous age [2] ; but Franchi's interpretation [3] is no doubt correct, the more so as there is no passage from gneiss to granite, and the intrusive character of the latter is beyond question. Moreover, the Triassic beds on the eastern as well as the Permian on the southern periphery of the massif overlie the gneiss with marked unconformity, thus pointing to a long interval of deposition and therefore to a consider-

[1] The term " primitive " gneiss is used throughout this paper in its strictly stratigraphical sense as the " fundamental " substratum of all the more recent formations.

[2] F. Sacco, " L'Age du massif de l'Argentère " : Bull. Soc. géol. France, 1907, vi, p. 484 et seq. Also " Gruppo dell' Argentera " : Mem. R. Acc. Scienze, Torino, 1911, lxi, p. 457 et seq.

[3] S. Franchi, " Osservazioni lavori geol. Alpi Marittime " : Boll. R. Com. geol., 1907, p. 145 et seq. Among the excellent reports in the Boll. R. Com. geol., besides those already quoted in this and the preceding paper, are the following relating to the Cottian Alps :—

S. Franchi, " Tettonica della zona pietre verdi del Piedmonte," 1906, p. 118 et seq. ; " Appunti geol. e petrogr. Monti di Bussoleno," 1895, p. 3 et seq.

S. Franchi and V. Novarese, " Appunti geol. e petrogr. dintorni di Pinerolo," 1895, p. 385 et seq.

V. Novarese, " Rilevamento geol. Valle Germanasca," 1895, p. 253 et seq. ; " Rilevamento geol. Valle Pellice," 1896, p. 231 et seq.

A. Stella, " Rilevamento geol. Valle Varaita," 1895, p. 283 et seq. ; " Rilevamento geol. Valle Po," 1896, p. 268 et seq.

able difference of age between the gneiss and the overlying younger formations.

2. *The Monte Viso Group.* (Figs. 1 and 2.)

This area forms an elongated lenticular ellipsoid from south to north, about 40 kilometres in length and 2 to 6 kilometres in width, between the Maira Valley at its southern and the Pellice Valley at its northern end, while nearer the centre on its southern side it is cut by the Varaita Valley. In the centre itself, on the eastern side, rises the Po, which, although in its lower course it collects the drainage of all the rivers of the Piedmontese Alps, is, in its upper torrential and cascade course, the shortest of all.

The majestic appearance of Monte Viso—Pliny's *Mons Vesulus*—is largely owing to the surrounding area of calc-schists having been considerably lowered by erosion which scooped out a socket-like depression round the base of the more resistant pietre verdi mass and thus made the pyramid—the highest point of the Cottian Alps—all the more imposing. Close to it rise two similarly shaped but lower spurs: Visomut on its eastern side, and Visolotto grafted on its western flank, all three being in their upper or pyramidal parts composed entirely of pietre verdi. The same applies to Colle delle Traversette (3,287 m.) at the western, to Monte Granero (3,170 m.) at the northern, and to Lobbie di Viso (2,990 m.) at the southern end of the group, which thus forms an enormous lenticular mass in the calc-schist formation, parallel to the Dora–Maira gneiss massif which separates it from the Po plain.

1. *The Pietre Verdi Area of Monte Viso.*—The least difficult access to the central part of the group for examining the pietre verdi series is from Barge (500 m.) to Paesana and thence up the Po ravine to Crissolo (1,335 m.) and to the summit of Monte Viso (3,843 m.), the four stages being (1) the eastern mica-schist zone to Paesana; (2) the Dora–Maira gneiss massif, in the ravine or *chiusa* of which the Po is joined by the torrent Lenta; (3) the western mica-schist, and then the predominant calc-schist formation with the quarried crystalline limestone beds of Crissolo; and (4) the pietre verdi up to the summit.

The base of the Visomut spur discloses a great bank of serpentine passing to schist, at least 500 metres in thickness, followed to the top by alternating banks of gneissiform euphotide and euphotidic and amphibolic schist, the former conspicuous by smaragdite, the latter by its epidotic veins, both of which minerals are largely prominent throughout the whole Monte Viso group. The depression between Visomut and Monte Viso, in which are embedded Lago Grande and other tarns, is composed of calc-schist, chloritic and serpentinous schist. From this point the succession of pietre verdi banks can be traced uninterruptedly to the summit of Monte Viso along the path leading from the Quintino Sella refuge (about 3,000 m.) up the southern flank. From the refuge, which is built on a felspathic

euphotide bank, to the summit, the flank presents a series of alternating banks—as shown in the section, Fig. 2 [1]—of euphotide, epidotic, amphibolic, actinolitic, and prasinitic schists from 200 to 300 metres in thickness, with smaller intervening banks of serpentinous schist. The euphotide, varying from compact to schistose, is largely of porphyritic texture with greyish violet felspar and diallage altered to smaragdite. The amphibolic and prasinitic schists and their varieties predominate largely, and, together with euphotide, constitute the summit of Monte Viso, as they also do that of the almost perpendicular peak of Visolotto. In all the alternating banks the gradual passage into, and compenetration with each other is very marked, and so is more especially the tendency to chloritic decomposition forming serpentinous schist, which in contact with narrow bands of crystalline limestone imparts to the latter its greenish colour.

The descent from Monte Viso may, on the southern side, be conveniently effected by the Forciolline gorge, and thence through the Vallante ravine and the Varaita Valley by Sampeyre and Vernasca to Saluzzo in the Po Valley. In those deeply eroded ravines the calc-schist formation reappears in contact with amphibolic, prasinitic, and serpentinous schist. At the junction of the Vallante and Varaita Valleys the last-named schist predominates, and lower down the latter valley is replaced by alternating banks of calc-schist, serpentine, and chloritic amphibolite.

2. *The Gneiss, Mica-schist, and Graphitic Area.*—Parallel to and east of the pietre verdi area of Monte Viso runs, as already mentioned, the Dora–Maira primitive gneiss massif, about 60 kilometres in length and 5 to 10 kilometres in width, at an altitude of 1,500 to 2,000 metres, the visible thickness being about 700 to 1,000 metres. Its superficial continuity is, however, frequently interrupted by great intervening, overlying, or intercalated masses of minute, granular, and tabular gneiss, with which are associated masses of crystalline limestone, quartzite, steatite, and dioritic, amphibolic, and prasinitic rocks. The primitive gneiss is the typical rock with large elements, glandular, often granitoid, and tourmaliniferous; the mica-schists, often garnetiferous, and the minute, tabular gneiss flank the primitive gneiss both on the eastern and western side. Of the gneissoid dioritic rocks associated with the minute and tabular gneiss, which latter reaches, e.g. in the Pellice Valley, a thickness of 1,500 metres, an intercalated mass 700 metres in thickness occurs near Barge; another, 1,000 metres, near Angrogna (Pellice); and, again, in the Chisone Valley, another, 1,500 metres in thickness, where the dioritic rock is associated with and altered to amphibolites

[1] This section, p. 37, is founded on Zaccagna's great transverse section west to east of 70 km. from St. Paul in Dauphiné through the calc-schist formation, Monte Viso, and the Dora–Maira massif to Rocca Cavour in the Po Valley (Boll. R. Com. geol., 1887, p. 416, tav. ix). Franchi gives a similar section of the Monte Viso group at a lower level further south (ibid., 1898, p. 482, tav. ix; also Stella, ibid., 1896, p. 288).

and prasinites, including the ovardite of Fenestrelle. Both the tabular gneiss and the crystalline limestone, often associated with steatite, are extensively quarried on the eastern side of the Dora–Maira massif, at Vernasca in the Varaita, near Luserna in the Pellice, and near Malanaggio, etc., in the Chisone Valley, as are also the fissile, tegular, quartzite masses (*bargiolina*) of Monte Bracco (1,305 m.) near Barge.

In the same mica-schist and minute gneiss horizon occur masses of graphitic rock with intercalations of graphite, which, flanking Monte Bracco on its western side, extend about 20 kilometres south, and about the same distance north of Barge. It is here, in the Pellice and Chisone Valleys, that the graphitic zone is associated with the gneissoid dioritic rocks already mentioned. The whole mica-schist, minute gneiss, graphitic and dioritic zone is now assigned to the Permo-Carboniferous.

3. *Summary.*—The Monte Viso and Dora–Maira areas may be grouped, in ascending order from east to west, viz. from Barge in the Po Valley to Crissolo and the summit of Monte Viso, in a distance of 20 kilometres, in four horizons as follows :—

		Altitude. m.	*Visible depth.* m.
I.	Primitive gneiss of Dora–Maira massif, glandular to granitoid	500–2,000	1,500
II.	Mica-schists, minute, tabular, and graphitic gneiss with quartzite, crystalline limestone, steatite, graphite, and dioritic rocks		
III.	Calc-schists with crystalline limestone, serpentine, and amphibolic schists	1,300–2,000	700
IV.	Pietre verdi to summit of Monte Viso ; serpentine and serpentinous schist ; epidotic amphibolites ; glaucophanic prasinites ; actinolitic, chloritic, and talcose schists ; euphotides, gneissiform, porphyritic, and schistose	2,000–3,800	1,800
			3,300

The total visible thickness between the extreme points—exclusive of the fall of level in the depression between the gneiss massif and the calc-schist horizon on the western flank of the former—is thus 3,300 metres.

The fact that the mica-schist horizon flanks the gneiss massif on both sides, but on the eastern side along the base, viz. at a lower level, led Gastaldi to regard this reversal of the normal sequence as evidence of a zonal subsidence (*sprofondamento*), the more so as both formations dip below the valley floor and reappear about 6 kilometres east in the isolated outcrop of Rocca Cavour (460 m.). Zaccagna, on the other hand, explained the phenomenon as an anticlinal retroflex fold of the gneiss massif from west to east. As a zonal fracture or subsidence, it bears close analogy to similar zonal phenomena in Northern Piedmont, to which I shall refer in the sequel.

V.

The Crystalline Formations of the Piedmontese Alps.

II. Western Piedmont.

The Dora Riparia Groups. (Figs. 3 and 4.)

In these groups shown in the sketch-plan Fig. 4, may be included the interesting pietre verdi areas (1) of the Rocciavré ridge on the right, (2) of Monte Rocciamelone on the left side of the Dora Riparia Valley, and (3) of the Rocciacorba ridge and the Avigliana belt of spurs where the Dora and the Sangone Rivers emerge from the Alps and enter the Po Valley about 20 kilometres west of Turin.

1. The Rocciavré Group.

This ridge, about 12 by 4 kilometres in length and width, forms the divide between the Dora Riparia and Chisone Valleys, north and south respectively, while its eastern end lies at the head of the short valley of the Sangone torrent which discharges into the Po at Moncalieri south of Turin. Although the ridge derives its name from Monte Rocciavré, the latter (2,778 m.) is only one and not the highest of a remarkable cluster of pietre verdi peaks ranging from 2,600 to 2,900 metres in altitude. Of these the most notable are Rocciavré, Cristalliera (2,801 m.), Pian Real (2,617 m.), and Rocca Rossa (2,391 m.) at the eastern, Gavia (2,841 m.), Rocca Nera (2,852 m.), and Mezzodi (2,777 m.) at the northern, and the highest peak Orsiera (2,878 m.) at the western end, the elevation thus decreasing from west to east. The whole ridge obviously represents a former extensive pietre verdi sheet or cupola cut up by erosion and atmospheric denudation into resistant peaks which are separated by high *colli* or saddles of about 2,500 metres altitude.

The high-level pietre verdi area is accessible either from Perosa in the Chisone Valley (700 m.) or from Bussoleno (500 m.) in the Dora Valley, on which latter side the flanks of the ridge are deeply cut by several torrents in cascade gullies or *orridi*.[1] On the Chisone or southern flanks one of the most remarkable exposures, pointed out by Gastaldi as early as 1876,[2] is that near Colle della Roussa, about 2,400 metres altitude, where the substratum of minute and tabular gneiss with intercalated crystalline limestone, steatite, and graphitic

[1] These cascade gullies, varying from 100 to 300 metres in height, are characteristic of the mountain-sides of the Dora Riparia Valley, and are locally called *orridi* both from their weird, forbidding appearance and the enormous quantities of detritus and débris brought down through them by the torrents when in flood.

[2] Boll. R. Com. geol., 1876, p. 108.

Fig. 2. SECTION OF MONTE VISO.

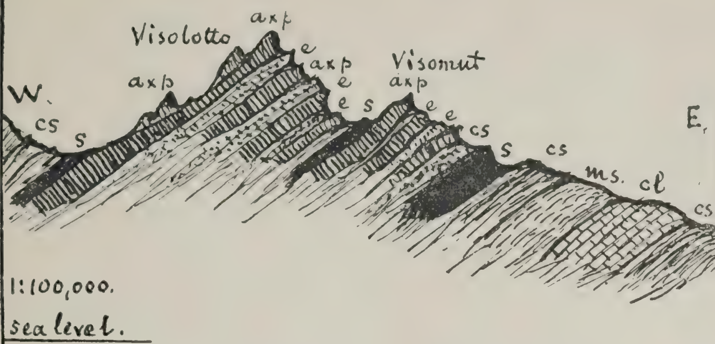


Fig. 3. SECTION OF ROCCIAMELONE.

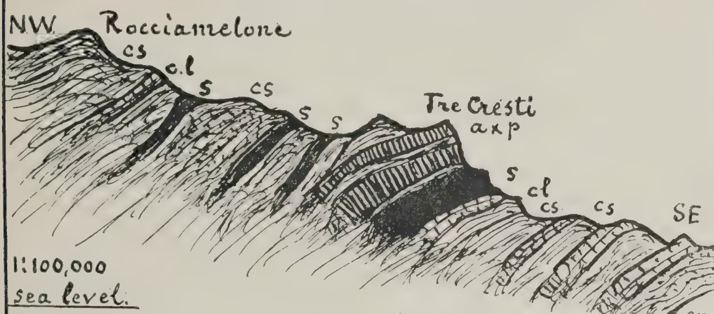
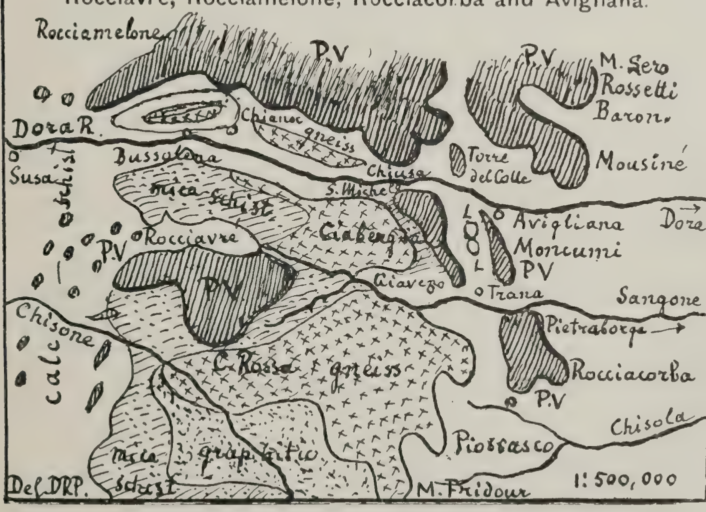


Fig. 4. THE DORA RIPARIA GROUP.

Rocciavre, Rocciamelone, Rocciacorba and Avigliana.



cs = calc-schist ; ms = mica-schist ;
cl = crystalline limestone ; s = serpentine ; e = euphotide ;
axp = amphibolites and prasinites.

rock is overlain horizontally and conformably by a great bank of lherzolite more or less altered to serpentine, both compact and schistose, upon which rests an equally high bank of euphotide largely metamorphosed to amphibolic and epidotic rock with smaragdite, and to glaucophanic prasinites. The total thickness of this pietre verdi exposure is at least 200 metres.

Unlike the southern or Chisone flanks, which form part of the gneissic-graphitic zone, the northern or Dora Riparia flanks of the ridge exhibit from Bussoleno (500 m.) upwards the normal crystalline sequence of mica-schist with gneiss intercalations at the lower, and calc-schists with pietre verdi at the higher levels. The Bussoleno gneisses, quarried on the right of the Dora down to Villar Focchiardo, differ greatly from the primitive, large-grained, glandular eye-gneiss of the Dora-Maira massif which crops out on both sides of the valley from Villar Focchiardo to S. Michele. Those younger, intercalated gneisses are of the minute and tabular type, in part with porphyroid and eye-structure, more or less tourmaliniferous, often rich in albite and poor in mica, or vice versa, while the mica-schist is frequently garnetiferous.[1] Such gneiss intercalations also occur higher up the ridge, where they are associated with omphacitic eclogite and prasinite.

The pietre verdi area of the ridge as a whole may be described as composed of peridotitic, serpentinous, and euphotidic masses extending in the shape of a triangular trough from the Orsiera peak at the western to Colle della Rossa at the southern, and to Rocciavré, Pian Real, and Rocca Rossa at the eastern end, while euphotides and prasinites predominate more especially in the Rocca Nera and Mezzodi peaks in the centre of the northern part. The serpentinous masses reach their maximum thickness of about 300 metres in the Orsiera, and of 500 metres in the Pian Real peak. The contact between serpentine, euphotide, and prasinite is generally marked by serpentinous, chloritic, and actinolitic schist, and in places by eclogite with large uralitized omphacite crystals, while the chloritic schist, e.g. between Pian Real and Rocca Rossa, contains diallagic, viz. smaragdite, crystals of unusually large size.[2] The euphotides present a great many varieties and are, as usual, largely altered to their prasinitic and zoisitic derivatives.

In the total rise of 2,300 metres from the valley floor near Bussoleno to the crest-line of the ridge, the garnetiferous mica-schists, with tourmaliniferous gneiss intercalations and quartzite, occupy about 1,200 metres, followed by about 600 metres of calc-schist with

[1] The gneisses of Bussoleno are among those regarded by Professor Gregory as intrusive and Pliocene ("Waldensian Gneisses": Q.J.G.S., 1894, p. 232 et seq.). His views were traversed in detail by Franchi, "Appunti Monti di Bussoleno": Boll. R. Com. geol., 1895, p. 177 et seq., and by Novarese, "Rilevamento Valle Germanasca": ibid., 1895, p. 277 et seq.; also by Stella, "Valli Orco e Soana": ibid., 1894, p. 349, footnote.

[2] Franchi mentions such crystals up to 20 centimetres in length. Op. cit., 1895, p. 3 et seq.

intercalated prasinitic and serpentinous schist, and lastly by about 500 metres of pietre verdi forming the cupola of the ridge.

The ravine of the Sangone east of the ridge to Giaveno, where the torrent enters the Po Valley, is deeply and entirely eroded in the gneiss and mica-schist of the Dora-Maira massif without pietre verdi, but in other directions the Rocciavré group is linked with large pietre verdi areas both past and present. Thus, on the north the pietre verdi extend across the Dora Valley to Rocciamelone and the Lanzo valleys, while west, south-west, and south a large number of small intermittent outcrops afford evidence of a former extensive area which lay in the great syncline of the calc-schist formation 20 to 25 kilometres in width,[1] and connected the Rocciavré group with the similar groups of Oulx, Chaberton, Genèvre, Maurin, Chabrière, and Monte Viso.

2. The Rocciamelone Group.

This imposing mountain, the ancient *Mons Romuleus*, with its peaked summit, rises straight from the Dora Riparia on the left of the valley at Susa (503 m.) to an altitude of 3,537 metres in a horizontal distance of only 7 kilometres. The most accessible ascent is from Susa or, further down the valley, from Bussoleno. The massif lies in the calc-schist horizon, which also includes the series of similar high peaks immediately north of it, as far as the Levanna and Gran Paradiso gneiss massif. From the summit and the sanctuary of Madonna della Neve down the southern flank the calc-schist alternates at first with micaceous schist, lenticular masses of bluish and white crystalline limestone, serpentine with ophicalce or green marble, and amphibolites and prasinites, as far as the spur of Tre Cresti. From this point in an oblique direction towards Bussoleno and Chianoc, the alternations of calc- and micaceous schist with pietre verdi become more frequent, and nearer the valley floor are replaced by minute and tabular gneiss, intercalated masses of crystalline limestones, and the fossiliferous calcareous beds of Chianoc and Foresto.

On this southern flank, shown in the section Fig. 3, the pietre verdi exhibit remarkable aggregations of amphibolic and prasinitic rocks with both massive and schistose serpentine, which latter becomes so predominant as to eclipse the calc-schist altogether. Especially is this the case in and above the Rio Muletta gorge, which descends to Bussoleno from the Croce di Ferro ridge, and exhibits an almost perpendicular cliff of serpentine no less than 500 metres in height, overlain by another 500 metres of amphibolites and prasinites. The serpentine cliff rests on crystalline limestone which then alternates

[1] The calc-schist formation extends north-west, and entirely encircles the mica-schist and minute gneiss massif of Rocca d'Ambin (3,377 m.), about 20 by 10 kilometres in length and width, which lies between the upper Dora Riparia Valley on the Italian and the Are Valley on the French side, and at its northern extremity is crossed by the Mont Cenis road from Lanslebourg to Susa. As already mentioned in No. III, p. 23, of this volume, the calc-schist area with pietre verdi of Southern Piedmont west of Monte Viso is probably an overthrust from the Dauphiné side of the Alps.

with calc- and serpentine-schist down to the minute and tabular gneiss near Chianoc, the latter belonging to the same horizon as the Bussoleno gneisses on the opposite side of the valley. Lower down the valley, as already mentioned, the typical primitive, glandular gneiss with large elements and greyish-green mica appears on both sides, extending on the left to St. Didero, Borgone, and Condové, and on the right to St. Antonino, Vayes, and the *chiusa* or defile of S. Michele. In this section of about 12 kilometres the bed of the Dora Riparia is therefore eroded entirely in primitive gneiss, which here forms the northern extremity of the Dora-Maira gneiss massif.

The crest of the great ridge of peaks and crags which runs on the left of the Dora from Rocciamelone eastward for about 36 kilometres to the spur of Monte Musiné, north-east of Avigliana, is almost entirely composed of pietre verdi with only a few narrow outcrops of calc-schist in the intervening eroded saddles or *colli*. As this ridge forms more properly part of the area of the Lanzo valleys, I shall refer to it again in connexion with that region.

3. The Rocciacorba and Avigliana Group. (Fig. 4.)

This group is of special interest, owing alike to its complex nature and its singular configuration, and also because of its vicinity to Turin, whence it is easily reached by Rivoli, Giaveno, or Avigliana. As already mentioned, the eastern spurs of the Dora Riparia and Sangone Valleys converge to a horseshoe or amphitheatre—about 25 kilometres in circumference and 10 kilometres in width—in the centre of which lies Avigliana. The southern end of the horseshoe, on the right of the Sangone, is formed by the Pietraborga spur (926 m.) of the Rocciacorba ridge, the middle or western part by the Ciabergia (1,178 m.) and Sacra S. Michele (962 m.) spurs between the Sangone and Dora Riparia Valleys, and the northern bend, on the left of the Dora, by the promontory of Torre del Colle (600 m.), and the mountain-side comprising, among others, Rocca della Sella (1,508 m.), Monte Curto (1,325 m.), and, at the eastern extremity, Monte Misuné (1,150 m.). Across the centre of the horseshoe, as a connecting link between the Pietraborga and Torre del Colle spurs, stretches the low Moncumi (642 m.) and Avigliana ridge, and between this and the Ciabergia or western spur lie, in an old morainic depression, the two small lakes of Avigliana (452 m.). From the Moncumi ridge eastward spread the enormous glacial and alluvial deposits of the Dora Riparia, sloping down towards Rivoli and Turin, referred to in a previous paper.[1] On the rugged and precipitous flanks of the horseshoe, patches of glacial deposits reach up to 900 metres altitude or 500 metres above the valley floor, but the continuity of the rock formations can be traced all round the crags and in the numerous gullies or *orridi* of the different spurs.

The pietre verdi of this area lie in the horizon of minute gneiss and mica-schists, which are, however, in evidence only in outcrops on the

[1] "The Moraine Walls and Lake Basins of Northern Italy," No. I.

western margin, at the base of the primitive gneiss, and therefore in reversed sequence, as the continuation of the corresponding reversal further south, already referred to. The minute gneiss and mica-schists with crystalline limestone form banks of considerable thickness on the Ciabergia and S. Michele ridge where they are quarried. Together with the pietre verdi on their eastern margin, they are the continuation of the gneissic, dioritic, and peridotitic belt of the Rocciacorba ridge, which, about 8 by 3 kilometres in length and width and about 900 metres in altitude, extends from Monte S. Giorgio, near Piossasco, on the south, to the Pietraborga spur above Trana at its northern end. The crest-line of this ridge exhibits in succession the masses of garnetiferous and graphitic mica-schist and minute gneiss, lherzolite, serpentine, and dioritic rocks with associated eclogite, and amphibolic and prasinitic schists which constitute the series and reach their greatest thickness in Monte Montagnazza (892 m.).

From the Pietraborga spur the pietre verdi radiate N.W., N., and N.E. in several more or less defined zones, of which the western follows the Ciabergia ridge, crosses the Dora Riparia at S. Michele, and reappears on the left bank at Chiavrié, while the middle zone, starting from the same point, forms the Moncumi and Avigliana ridge between the Sangone and the Dora, and reappears on the left of the latter at Torre del Colle ; and a third zone, bifurcating from the second at the Moncumi ridge, crosses the Dora, and, running north-east, forms the Musiné spur. Within the Avigliana horseshoe, the pietre verdi thus attain a visible thickness of 500 metres in Monte Pietraborga, of 700 metres in the Ciabergia ridge, and of 1,200 metres and more on the mountain-side left of the Dora, whence the series continues north for about 25 kilometres along the eastern spurs to Lanzo. It is in this belt that the peridotitic masses, lherzolite and serpentine, with associated euphotide, are more especially predominant. In places, e.g. in the Musiné spur, the lherzolite is so decomposed that it is quarried for the extraction of magnesite.[1] All the pietre verdi masses of the Rocciacorba and Avigliana area dip at more or less steep angles, in some places are almost vertical, and throughout are much contorted.

The three groups of the Dora Riparia area, viz. of Rocciavré, Rocciamelone (in the triangle Susa, Chianoc, and summit), and Rocciacorba and Avigliana, cover each about 50, in the aggregate 150 square kilometres, or about 60 square miles, equal to the superficial area of the Monte Viso group. The conclusions as to the age and origin of the pietre verdi groups of Southern and Western Piedmont considered in the present paper, will be stated in connexion with the areas of Northern Piedmont to be dealt with in the sequel.

[1] The quarried exposure of lherzolite with euphotide and magnesite is on the south-east slope of Monte Musiné, above Casellette (505 m.). About 8 km. east of this point, midway between it and Turin, lies, at Pianezza, in the morainic area, Roc Gastaldi, an erratic monster-block of euphotide measuring 30 by 12 by 14 metres in length, width, and height = 5,000 cubic metres or over 10,000 tons. It is surmounted by a small chapel.

VI.

The Crystalline Formations of the Piedmontese Alps.

III. Northern Piedmont.

IN the preceding papers [1] I described the crystalline rock areas of the Maritime and Cottian Alps : I now proceed to briefly review those of Northern Piedmont forming part of the Grajan and Pennine Alps, under three heads—

1. The Lanzo Valleys and Gran Paradiso Groups.
2. The Dora Baltea (Val d'Aosta) Groups.
3. The Lanzo, Ivrea, and Val Sesia Groups.

They are shown in the sketch-map, Fig. 1. The conclusions in reference to the combined areas of the Piedmontese Alps will be stated at the end of the present paper.

1. The Lanzo Valleys and Gran Paradiso Groups.

1. *The Lanzo Valleys* (Figs. 1 and 3).—The Stura di Lanzo emerges from the Alps and enters the Po Plain close to the town of Lanzo (540 m.) about 30 kilometres north-west of Turin, and discharges into the Po a short distance below that city. The point of exit lies immediately west of Lanzo, where the Stura cuts through a lherzolite wall 400 metres in height. This defile, or *chiusa*, of St. Ignazio, 3 kilometres in length, thus forms the gateway and drainage exit of what is undisputably the largest, most concentrated, and most diversified pietre verdi area in the Alps, covering, as it does, no less than 600 square kilometres or about 240 square miles. Immediately west of the St. Ignazio defile the Stura divides into two branches—the southern or Stura d'Usseglio, and the northern or Stura Val Grande—from which latter branches off, a few kilometres higher up, at Ceres, the western arm or Stura di Balme. The more or less parallel courses of the three torrents from their sources to their confluence near St. Ignazio are from 20 to 30 kilometres in length. The Usseglio Stura rises in Rocciamelone (3,557 m.), the middle or Balme Stura descends from Uja Bessanese (3,622 m.) and Uja Ciamarella (3,670 m.), and the Val Grande Stura has its source in La Levanna (3,555 m.). Of these four mountains, forming a crest-line of barely 15 kilometres south to north along the Franco-Italian frontier, the first three constitute a formidable calc-schist massif, while the treble-peaked Levanna forms part of the Gran Paradiso gneiss massif. The Usseglio and Balme Sturas have eroded

[1] Nos. IV and V of this volume.

Fig. 1. Sketch Map of Crystalline Rock Areas, Northern Piedmont.

PV = pietre verdi ; D = diorite ; gr = granite ; por = porphyrite ; sy = syenite ; s = peridotite and serpentine ; gn = gneiss ; MS = mica-schist.

Del: D.R.P.

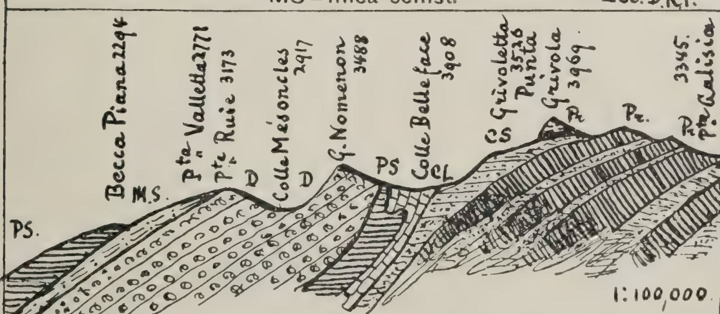


Fig. 2. Section of Grivola Ridge, Grajan Alps.

PS = Permo-Carboniferous schist ; MS = mica-schist ; D = diorite ; CL = crystalline limestone ; CS = calc-schist ; Pr = prasinites.

their beds chiefly in pietre verdi, while the Val Grande branch lies, in its upper part, exclusively in the gneiss formation, and traverses pietre verdi masses only in its lower course. The floors of the three valleys are from 1,000 to 2,000 metres below the crest-lines of the dividing ridges with steep, often almost vertical mountain sides.[1]

As is seen from the sketch-plan, Fig. 3, the drainage area of the Lanzo valleys forms approximately a rectangle about 30 by 20 kilometres in length and width, enclosed by four ridges whose extreme points are Rocciamelone and Levanna on the west and Monte Arpone, Lanzo, and Cima Angiolino on the east.[2] Within these ridges, the Lanzo valleys with their three parallel divides form a trough or syncline of pietre verdi in two unequal parts : the larger, western part, about two-thirds of the whole, which lies in the calc-schist, and the smaller, eastern part, about one-third of the whole, which lies in the mica-schist formation. These two juxtaposed divisions or old centres of eruption of different age are separated by a narrow strip of calc-schist running south to north from Monte Arpone to Ceres and Monte Bellavarda, as shown in Fig. 3. On the north, the western division is bounded by the Gran Paradiso gneiss, and the eastern division by mica-schist and minute gneiss. The Paradiso gneiss, being the fundamental substratum, probably extends south below the calc-schists and pietre verdi to the Dora-Maira gneiss massif ; the mica-schist formation with pietre verdi is the continuation of the Rocciacorba and Avigliana belt south of the Lanzo valleys and extends north-east from Lanzo to Ivrea and Val Sesia. The calc-schists are in evidence chiefly at the lower levels of the valleys where they alternate with peitre verdi ; at the higher levels and on the crest-lines they are very subordinate, and, except on the western ridge from Rocciamelone to Cimarella, and in the dividing strip already mentioned, appear only in the eroded gaps or saddles of the more resistant pietre verdi masses.

From Mattirolo's beautiful " geo-lithological " contour-map of the Lanzo valleys 1 : 100,000 (1904),[3] the distribution of the crystalline rocks of the entire area works out approximately as follows :—[4]

[1] The three Stura valleys, as also the Orco Valley (Gran Paradiso), are easily accessible by roads leading to Usseglio, Palme, Forno, and Ceresole, at the upper ends, 1,265, 1,458, 1,226, and 1,613 m. altitude respectively. The Usseglio and Balme Valleys are also known as the Viù and Ala Valleys respectively.

[2] The short valley of the Tesso, immediately north of Lanzo, lies, strictly speaking, outside the drainage area of the St. Ignazio defile, but the torrent, rising in Cima Angiolino, belongs to the Stura watershed and forms part of the Lanzo valleys.

[3] Boll. R. Com. geol., 1905, p. 191. At the time of the compilation of this map all the crystalline rocks of the Lanzo valleys were still considered of Archæan age without distinction between the age of the mica-schist and the calc-schist formation, the new classification dating from 1911.

[4] The earlier works dealing with the Lanzo valleys, etc., by Gastaldi, Strüver, Baretti, and Bucca from 1871 to 1886 were already quoted in the preceding papers.

		sq. km.		per cent
Lias-Trias (western division)	Calc-schist with crystalline limestone	48	=	8
	Pietre verdi	240	=	40
Permo-Carboniferous (eastern division)	Mica-schist and minute gneiss. .	96	=	16
	Pietre verdi	120	=	20
Pre-Carboniferous.	Gran Paradiso gneiss	96	=	16
		600		100

The pietre verdi of the two divisions thus represent collectively no less than two-thirds of the aggregate area. The lithological distribution of those masses, intercalated in, and resting on the crystalline schists, is extremely complex, for, except the transverse dividing line already mentioned, there is in their kaleidoscopic association no demarcation, sequence, or distinction of level. Yet, on closer examination, the broad limits of certain groups can be defined along the four parallel ridges, which, flanking and separating the three valleys, run west to east and converge at the Lanzo defile. The principal groups, generally circumscribed by morainic, alluvial, and detritus belts round their bases, are shown in the plan, Fig. 3, and specified in the following table, in which the names and altitudes refer only to the culminating points. In almost every case the groups, varying in area from 5 to 20 square kilometres, comprise a cluster of minor peaks and spurs, and alike by their formidable bulk and their often pinnacled crests attest the great resistance of pietre verdi to denudation, to which the once overlying crystalline sedimentary schists more readily and long since succumbed.[1]

Distribution of Pietre Verdi in the Lanzo Valleys.

Ridge I, from Rocciamelone to Lanzo, on right of Usseglio Valley ; 36 *km.*

Serpentine : Gran Uja (2,686 m.) ; Civrari (2,302 m.).
Peridotite, lherzolite, and serpentine : Arpone (1,600 m.) ; Roc Neir (1,516 m.).

Ridge II, from Croce Rossa to Lanzo, between Usseglio and Balme Valleys ; 30 *km.*

Amphibolites, prasinites, and euphotides : Torre d'Ovarda (3,075 m.) ; Monte Ciaron (1,863 m.).
Serpentine : Becca Nona (2,765 m.) ; Morosa (2,135 m.) ; Calcante (1,644 m.).

Ridge III, from Ciamarella to Lanzo, between Balme and Grande Valleys ; 30 *km.*

Serpentine : Uja Mondrone (2,964 m.) ; Rosso (1,774 m.).
Amphibolites, prasinites, and euphotides : Doubia (2,464 m.) ; Plù (2,201 m.).

Ridge IV, from Levanna to Lanzo, on left of Val Grande ; 36 *km.*

Amphibolites, prasinites, and euphotides : Bellavarda (2,345 m.).

On the whole, serpentines predominate in the first, amphibolites, prasinites, and euphotides in the second ridge, while in the third

[1] The local designations Uja, Ciama, Punta, Becca, Bric, Truc, Torre, Rocca, etc., all denote point, peak, summit, crest, crag, etc.

the two series are about equal, and in the fourth they are only represented by the Bellavarda complex wedged between the gneiss formation on the left and the mica schists on the right. The two series of the calc-schist horizon share their aggregate area of about 240 square kilometres in fairly equal proportions ; that of the eastern or mica-schist horizon, occupying 120 square kilometres, is about equally divided between the nucleus of peridotite and lherzolite, and the surrounding belt of serpentine with associated euphotide.

The pietre verdi of the Lanzo valleys appear in all their varieties and at all levels from 500 m. altitude at Lanzo, which town is built on serpentine, up to 3,500 metres on the highest points of the central and enclosing ridges. At the lower levels, more especially in the central part of the synclinal trough, they alternate conformably with calc-schist and crystalline limestone intercalations, having shared in the acute folding and contortions of the latter ; while at the higher levels they form enormous banks, cliffs, and bastions, like separate massifs, such as the serpentine complexes of Gran Uja, Civrari, Becca di Nona, and Uja di Mondrone, and, again, the amphibolic, prasinitic, and euphotidic groups of Torre d'Ovarda, Ciaron, Doubia, and Bellavarda mentioned in the table.

The chloritic prasinite known as ovardite and mentioned in paper III, p. 24, takes its name from the Torre d'Ovarda group in the Balme Valley, which latter is, moreover, famed for its splendid specimens of garnet, epidote, and other crystals. All the pietre verdi of more or less secondary composition and their schists present their usual actinolitic, glaucophanic, zoisitic, chloritic, and talcose varieties, and are often garnetiferous and eclogitic. They all exhibit the usual marked tendency to chloritic decomposition, i.e. to pseudo-serpentine or serpentinous schist, a phenomenon which applies equally to the peridotites, lherzolites and associated euphotides of the eastern or mica-schist horizon. In neither horizon do the euphotides appear as deep-seated rocks ; they are, on the contrary, associated and interstratified with the other pietre verdi at all levels, overlying and underlying, and intercalated in them and the crystalline sedimentary schists quite as often as vice versa. As in the areas of the Maritime and Cottian Alps previously described, so also in the Lanzo valleys the pietre verdi constitute two distinct, juxtaposed, and eminently magnesian series of eruptive and submarine origin, contemporaneous respectively with the Mesozoic calc-schist and the Permo-Carboniferous mica-schist formations with which they are intimately associated, and jointly with which they have for long periods been subjected to repeated earth-movements, folding, and intense pressure-, heat-, and hydro-metamorphism.[1]

[1] In a valuable memoir, "Contribuzione allo studio delle roccie a glaucofane etc., Liguria e Alpi Occid.," Boll. R. Com. geol., 1903, p. 255 et seq., S. Franchi has shown that the crystalline sedimentary rocks of the Piedmontese Alps, such as silico-calcareous schists (diaspri), quartzites, calc-schists and limestone, mica-schists, phyllites, and minute gneiss, contain glaucophane, epidote, sismondina, zoisite, chlorite, albite, and other secondary minerals as the result of metamorphism of associated and intercalated eruptive material.

2. *The Gran Paradiso Massif* (Fig. 1).—This oval-shaped complex, about 30 by 20 kilometres in length and width, is bounded on the south by the Lanzo valleys and on the north by the Dora Baltea watershed. At its southern extremity it is traversed by the Val Stura Grande already referred to, while its central part is intersected west to east by the Orco, which rises in Punta Galisia (3,345 m.) and with its affluent the Soana discharges into the Po. In the northern part rise the Cogne and Savaranche torrents, both of which drain into the Dora Baltea near Villeneuve, above Aosta. The Orco Valley has cut the original dome-shaped massif into two more or less parallel ridges, the southern from the treble-peaked Levanna to Monte Tovo (2,575 m.), and the northern which, starting from Punta Galisia, culminates in the classic ellipsoid or flat cupola of Gran Paradiso proper (4,061 m.), the highest point of the Grajan Alps.

The massif is composed of three more or less concentric masses, viz., a nucleus of primitive, granitoid, porphyroid, glandular, and eye-gneiss with large felspar crystals up to 10 centimetres, surrounded by an inner belt of smaller-grained, schistose, biotitic gneiss with green nodules, and an outer belt of mica-schist and minute gneiss, often with white mica. Of the biotitic gneiss a large lenticular mass in the primitive gneiss crops out at Ceresole (1,613 m.) in the upper Orco Valley, between La Levanna and Gran Paradiso. In this, the central part of the massif, the gneiss is bedded horizontally as the practically undisturbed fundamental substratum ; only the outer belt, more especially at the southern extremity, has shared in the folding and dipping of the Lanzo Valley region.[1] In juxtaposition to the outer belt, a more or less continuous fringe of calc-schist and pietre verdi extends all round the periphery of the massif, stretching from Monte Bellavarda in the Stura Grande Valley, north to the Orco and Cogne Valleys and thence north-east to the Champorcher and Clavalité Valleys, where it forms a separate, considerable area. Throughout this belt, the pietre verdi present all the varieties of those of the Lanzo valleys, including more especially glaucophanic amphibolites and omphacitic eclogite. Along its eastern margin this calc-schist and pietre verdi belt is contiguous to the mica-schist horizon with large intercalations of minute and tabular gneiss conspicuous by its green mica ; in the Lanzo valleys this gneiss is quarried near Pessinetto, between Lanzo and Ceres. The eastern spurs of the mica-schist area form part of the Lanzo-Ivera belt to be described later.

2. The Dora Baltea Groups.

The Val d'Aosta comprises in its middle course important pietre verdi groups, both on the right and left of the Dora Baltea. On the

[1] Novarese found a granite vein in a large erratic gneiss block near the Sea Glacier (2,500 m.), in the south-west corner of the Paradiso massif, which may therefore contain intrusive granite, like the Argentera massif in the Maritime Alps. V. Novarese, "Rilevamento Valli Orco e Soana, Alpi Occid." : Boll. R. Com. geol., 1894, p. 215 et seq. A. Stella, "Rilevamento Valle Orco, Alpi Occid." : ibid., p. 343 et seq.

right the most remarkable areas are those of Punta Grivola, Monte Emilius, and Monte Rafré, and on the left the Mont Mary group.[1]

1. *The Grivola Area* (Figs. 1 and 2).—About 10 kilometres north of Gran Paradiso, but outside the gneiss massif, and in the surrounding calc-schist formation, rises the Grivola peak (3,969 m.), which in its pyramidal grandeur vies with Matterhorn and Monte Viso. Its position is rendered the more commanding by the scooped out valleys of the Cogne on its eastern and northern, and of the Savaranche on its western flank, both of which torrents, as already mentioned, rise in the Paradiso massif and discharge into the Dora Baltea near Villeneuve (670 m.). The ridge which rises from Villeneuve[2] between the two valleys to the crest of Grivola and Grivoletta (3,526 m.) in a horizontal distance of 12 kilometres presents, in an interesting natural section, a complete sequence of rock formations which, in ascending order, may be summarized as follows :—

	Superficial width. km.	*Altitude.* m.
Villeneuve. *Lias and Trias :* Fossiliferous limestone, ordinary facies	4	700
Calc-schist and crystalline limestone		2,000
Becca Piana. *Permo-Carboniferous :* Sericitic, graphitic, gneissiform, and psammitic schist	1	2,800
Gran Nomenon. Sphenic diorite	4	3,500
Sericitic, graphitic, gneissiform, and psammitic schist	1	3,500
Grivola. *Lias and Trias :* Crystalline limestone, calc-schist, and prasinites	2	3,900
	12	3,200

The upper part of this section is shown in Fig. 4.[3] Its characteristic feature is the Permo-Carboniferous zone which crosses the ridge about midway between and at right angles to the calc-schist formation. The zone or belt is composed of an enormous mass of sphenic diorite which constitutes the Valletta, Ruié, and Gran Nomenon peaks and the intervening Mésoncles and Belleface cols or saddles, and is flanked on either side by considerable banks of sericitic, gneissiform schist and psammitic, carbonaceous sandstone of the greywacke type. The diorite zone, about 4 kilometres in superficial width, extends east into the Cogne Valley and west across the

[1] The whole region between the Aosta and Orco Valleys, including the Paradiso massif, is, perhaps more than any other part of the Piedmontese Alps, rendered conveniently accessible by the numerous mule paths of the Royal shooting preserves. An excellent topographical map of the Val d'Aosta, Lanzo, and Ivrea region, 1 : 250,000, is that by V. Novarese in Boll. R. Com. geol., 1913–14, p. 244, "Il Quarternario Valle d'Aosta e Valli Canavesi."

[2] Villeneuve is one of the localities where S. Franchi found fossils in Triassic limestone intercalated in calc-schists. "Terreni secondarie facies Piedmontese": Boll. R. Com. geol., 1909, p. 526 et seq.

[3] This section is founded on the complete one given by Novarese in "Profilo della Grivola": ibid., p. 497 et seq.

Savaranche Valley to Mount Bioulé on the divide between the latter valley and Val Rhêmes. In the Cogne Valley it was first recognized by Baretti [1] in 1876 and described as sphenic syenite, similar to the syenite of Biella ; but Novarese showed it to be essentially dioritic, with 63 per cent of SiO_2.[2]

The Savaranche and Cogne dark-green diorite varies in structure from compact to granitoid, gneissoid, and schistose, and is normally composed of plagioclase, hornblende, quartz, black mica, aggregations of minute muscovite, and abundant titanite (sphene) crystals up to 1 centimetre in length. Near Colle Mésoncles it exhibits secondary elements, e.g. albite, epidote, actinolite, with unaltered titanite, while on the Val Rhêmes ridge it is essentially fine-grained and massive. The mass thus presents an interesting example of this rock both in its primitive and in its metamorphosed, re-composed, granitoid, and gneissoid form. In upward succession the diorite and gneissiform schist zone is followed by a bank of crystalline limestone, and thence to the summit of Grivola and beyond to Punta Galisia [3] by a constant conformable alternation of calc-schist and pietre verdi banks, the latter up to 500 metres in depth, as part of the belt which encircles the Paradiso gneiss massif. Here again the pietre verdi, predominantly prasinites with strips of serpentinous schist, appear in all their varieties, more especially in the upper Savaranche Valley near Degioz (1,541 m.) immediately west of and below the Grivola peak, where the pietre verdi rocks contain fine specimens of gastaldite (blue glaucophane) and garnet crystals. The Permo-Carboniferous diorite and gneissiform schist zone of the Savaranche and Cogne Valleys is obviously connected with the similar diorite of Locana in the Orco Valley and of the Ivrea and Val Sesia belt to be dealt with later.

2. *Monte Emilius* (Fig. 1).—A striking contrast to the normal sequence of the crystalline sedimentary and pietre rocks of the Grivola group is presented by Monte Emilius (3,559 m.) and the neighbouring Becca di Nona (3,182 m.), which lie about 12 kilometres

[1] M. Baretti, "Studi Gruppo Gran Paradiso": Mem. Acc. Linceo Torino, 1876, p. 195 et seq.

[2] V. Novarese, "Diorite granitoide e gneissiche Val Savaranche": Boll. R. Com. geol., 1894, p. 275 et seq.

[3] The calc-schists of Grivola and Galisia were assigned to the Mesozoic (Lias-Trias) as the equivalents and continuation of the schistes lustrés by M. Bertrand in his "Etudes dans les Alpes françaises": Bull. Soc. géol. France, vol. xxii, p. 69 et seq., 1894, which marked his return from his temporarily Archæan to his earlier Mesozoic views on that formation. The latter were confirmed by P. Termier in "Les schistes lustrés de la Grivola": Bull. Service Carte géol. France, vol. vii, p. 150 et seq., 1895. The Piedmontese calc-schists are, on the whole, more micaceous than the French schistes lustrés, which are more aluminous than the former and to which the designation "série cristallo-phyllienne" is therefore more appropriate. The superposition of calc-schists on Triassic limestone as verified by Franchi and Termier in various localities also occurs in the Roches d'Ambin massif (Petit M. Cenis, upper Susa Valley), where the minute gneiss and mica-schist are overlain by Triassic limestone upon which rests calc-schist.

south-east of Grivola, and are separated from the latter by the Cogne Valley. Both mountains, with their extremely rugged and craggy flanks, rise straight from the Dora Baltea Valley between Aosta (580 m.) and St. Marcel to a height of 3,000 and 2,600 metres respectively in a horizontal distance of barely six kilometres. The upper parts and summits of both are composed of minute gneiss and eclogitic, garnetiferous mica-schist, while the lower flanks facing the Aosta Valley consist of huge masses of coarse-grained, gneissiform euphotide more or less parallel to the overlying gneiss and mica-schist. On the Monte Emilius flank the encircling calc-schist formation is not in direct evidence, but on Becca di Nona it crops out above Charvenod close to Aosta and again higher up at the Sismonda signal (2,347 m.), where it rests on minute gneiss. In both places the calc-schist dips at a steep angle in opposite directions, while the gneiss and mica-schist of the upper flanks and summits of both mountains are greatly contorted : near St. Marcel, at the lower end of the valley of that name, they descend to the 700 metres contour and then apparently dip below the calc-schist.

The phenomenon of reversed sequence in the Monte Emilius group is the result of an inverted fold in connexion with the great fracture fault which runs along the Aosta Valley to Chatillon and St. Vincent. From here, instead of following the sharp southward bend of the Dora Baltea towards Ivrea, it extends east across the Brusson Valley to Arcezas, where the calc-schist mass at the base of a great gneiss bank affords striking proof of a similar dislocation near the contact with the mica-schist formation of the Ivrea belt.

3. *Monte Rafré* (Fig. 1).—About 12 kilometres east of Monte Emilius, in the calc-schist and pietre verdi area of the Clavalité and Champorcher Valleys previously mentioned, occurs the remarkable sequence of the Monte Rafré (3,146 m.) and Monte Glacier (3,186 m.) group which forms the divide between those two valleys. In this case, a mass of brecciated prasinitic gneiss which crops out on the crest of the divide, overlies a mass of euphotide metamorphosed to prasinites, in apparently reversed sequence. In reality the prasinites, as Stella has shown,[1] are an isolated lenticular wedge intercalated in the brecciated gneiss which lies in the calc-schist formation. The latter, with pietré verdi, extends from the Champorcher Valley to Chatillon and Verrès in the Dora Baltea Valley and thence up the Tournanche and Brusson Valleys, whence it skirts the base of Matterhorn and Monte Rosa.

4. *Mont Mary.*—On the left of the Dora Baltea north of Aosta, and exactly opposite Monte Emilius, rises the Mont Mary (2,875 m.) group, which is the counterpart of the former and exhibits a similar reversed sequence. The calc-schist appears here at the base, and is overlain by Permian schist, upon which rests the cupola of garneti-

[1] A. Stella, "Gneiss Monte Emilius e M. Rafré": Bull. Soc. geol. ital., 1906, p. xlvi. E. Mattirolo, "Rilevamento Val Champorcher, Alpi Graje": Boll. R. Com. geol., 1899, p. 3 et seq.

ferous mica-schist. The group, which includes Gran Becca (2,967 m.) and Gran Col (2,864 m.), lies in the zone of the same fracture fault and presents the same phenomenon of an inverted fold as Monte Emilius on the opposite side of the valley. From the Mont Mary group the mica-schist formation extends up Val Pellina and across the crest of the Pennine Alps to Dent Blanche (4,364 m.), north-west of Matterhorn.[1]

The great intrinsic geological interest of the crystalline rock areas of the Aosta valleys described in the foregoing has in recent years been enhanced by Lugeon and Argand having included them in their grand series of overthrust sheets in that and other parts south of the crest of the Alps.[2] According to their theory, worked out from ingenious geometrical designs, the Gran Paradiso, Grivola, Gran Nomenon, Emilius, Rafré, and Mary groups are not "rooted" or "authochtonous" massifs, but cover-sheets (*nappes de recouvrement*) pushed over from different directions and more or less considerable distances. Investigations instituted by the Italian Geological Survey in 1905,[3] and notably by Novarese in 1909,[4] have, however, conclusively shown that the cupolas of those groups differ stratigraphically and lithologically from the "root" areas whence they are supposed to have been derived, and that, with the exception of the small, isolated massif of Monte Pilonet (2,697 m.) between the Tournanche and Brusson Valleys on the left of the Dora Baltea, where the gneiss cupola completely covers the calc-schist, there is no evidence at all of extensive overthrusts in that part of the Alps.

3. The Lanzo, Ivrea, and Val Sesia Area. (Figs. 1[5] and 4.)

This, perhaps the most complex crystalline area of the Piedmontese Alps, is also eminently *sui generis*, for it forms a unit of rocks outside, and different from the great calc-schist horizon with pietre verdi of secondary composition. As previously stated, it is the continuation of the mica-schist and minute gneiss belt which

[1] V. Novarese, "Gneiss Monte Emilius e M. Mary": Boll. Soc. geol. ital., 1912, p. 31. Novarese describes an interesting section of granite, mica-schist, and diorite in a railway cutting between Aosta and Quart, on the left of Dora, below M. Mary.

[2] M. Lugeon & E. Argand, "Grandes Nappes Recouvrement de la zone du Piedmont. Homologies ditto": Comptes rendus Acad. Sciences, Paris, Mai 15 et 29, 1905.

[3] "Relazione": Boll. R. Com. geol., 1906, p. 27.

[4] V. Novarese, "Profilo Grivola": Boll. R. Com. geol., 1909, p. 497 et seq. A. Stella, op. cit., 1912, p. xlvi. "Problema geo-tettonico Ossola e Sempione": Boll. R. Com. geol., 1905. p. 5 et seq. S. Franchi, "Tettonica della Zona del Piedmonte": ibid., 1906, p. 123 et seq.

T. Taramelli, in some recent memoirs *contra* long-distance overthrusts in the Alps and Apennines, has introduced the short and expressive term of *coltri* as corresponding to *nappes de recouvrement*. Rend. Ist. Lomb., xiv, p. 1009, 1913.

[5] For Sketch-map, Fig. 1, *vide* p. 43.

skirts the Po Valley from the Rocciacorba group to Avigliana, Monte Musiné, and Lanzo, and, extending from Lanzo to Ivrea, Biella, and Val Sesia, reaches beyond the latter into Lombardy to Lakes Orta and Maggiore. Within the Piedmontese Alps, viz. from Lanzo to Val Sesia, it is bounded on the north by the calc-schist and pietre verdi fringe which skirts the Monte Rosa gneiss massif, and on the south by the Pliocene and Pleistocene deposits of the Po Valley, its superficial area being roughly 90 by 15 kilometres or 1,350 square kilometres, equal to over 500 square miles. The lower hills of the southern margin vary from 600 to 900 metres in altitude, which in the centre of the area increases to 1,000 and at the northern margin to 2,500 metres. In its general direction south-west to north-east, the area is intersected more or less at right angles by the following affluents of the Po: Stura di Lanzo, Malone, Orco, Chiusella—Dora Baltea, Elvo-Cervo, and Sessera-Sesia. The valley floors vary at the lower limit of the crystalline area from 300 to 500, and in their upper parts from 600 to 1,000 metres in altitude.

As distinguished from the crystalline schist and pietre verdi zone of the Maritime, Cottian, and Grajan Alps, Gastaldi labelled the Lanzo-Val Sesia area the "external crystalline zone".[1] Gerlach,[2] as early as 1869, designated it as the Ivrea dioritic zone, from the conspicuous outcrops of diorite within and outside the great morainic amphitheatre of the Dora Baltea Valley around Ivrea, which town is itself built on diorite.[3] Within recent years it has come to be called the dioritic-kinzigitic zone, chiefly in consequence of Franchi's and Novarese's surveys,[4] and in order to give due prominence to the eclogitic gneiss formation in the Sesia Valley and east of the same, which has its equivalent in the Kinzig Valley of the Black Forest, where it was first recognized and so named by Fischer as early as 1863. Another equivalent formation is that of the hilly area near Monteleone, bordering on the Mediterranean in Calabria.[5] In all the three cases, the rock, greenish brown in colour, gneissic in aspect and structure, but more fine-grained, micaceous, and less quartzose than primitive gneiss, is often granitoid, and, besides triclinic felspar and quartz, contains garnet, omphacite, biotite, sillimanite, and graphite as associated minerals.

[1] Gastaldi, "Studi geol. Alpi Occid.": Boll. R. Com. geol., 1871, p. 3 et seq.

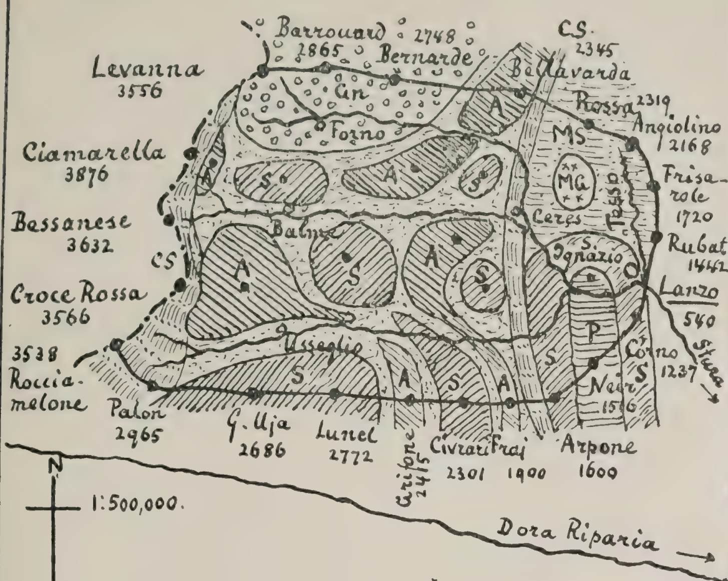
[2] Gerlach, Die Pennischen Alpen, 1869.

[3] The lakelets S. Michele, Campagna, Sirio, Pistone, and Nero immediately north of Ivrea, near Montalto, within the moraine wall of Serra d'Andrate, all lie in the diorite zone.

[4] C. F. Parona, "Valsesia e Lago d'Orta": Atti Ist. Lomb., vol. xxix, Milano, 1886. V. Novarese, "Trattato Weinschenk Zona d'Ivrea": Boll. R. Com. geol., 1905, p. 181 et seq.; "Zona d'Ivrea": Boll. Soc. geol. ital., 1906, p. 176 et seq. S. Franchi, "Zona dioritica-kinzigitica Ivrea-Verbano": Boll. R. Com. geol., 1906, p. 270 et seq.; "Anfibolo secondario del gruppo glaucofane in una diorite di Val Sesia": ibid., 1904, p. 242.

[5] R. Ugolini, "Kinzigite di Monteleone, Calabria": Atti Soc. toscana Pisa, 1911, p. 55 et seq.

Fig. 3. Sketch Plan of Lanzo Valleys, Grajan Alps.



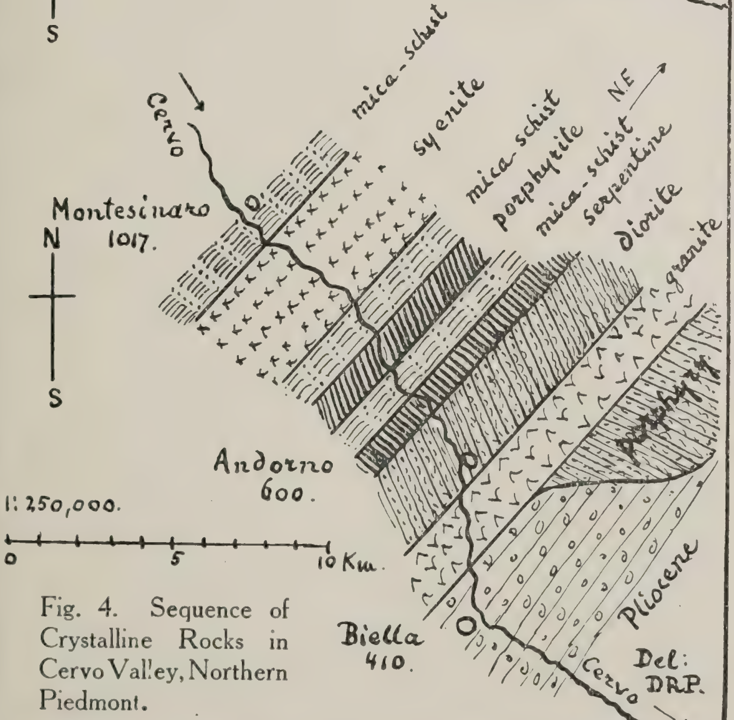


Fig. 4. Sequence of Crystalline Rocks in Cervo Valley, Northern Piedmont.

Fig. 3. S = serpentine; A = amphibolites, prasinites and euphotides; P = peridotite and lherzolite; CS = calc-schist; MS = mica-schist.

From Lanzo to Val Sesia, the sedimentary crystalline formation concomitant with the Sesia gneiss is that of eclogitic mica-schists, viz. with garnet, omphacite, and blue glaucophane, corresponding to those of the Aosta Valley.[1] With the mica-schists and occasional minute gneiss intercalations are associated dark-greenish, sericitic, calcareous, and quartziferous Permian schists. Both are overlain here and there by isolated masses or patches of Middle Triassic, more or less crystalline and dark dolomitic limestone, the remnants of a much more extensive formation removed by denudation. In the mica-schist formation are intercalated—

(1) The continuous belt of biotitic and amphibolic diorite which covers 50 by 5 to 10 kilometres in length and width, and is flanked on its southern margin by granite, and on its northern margin by minor belts of peridotite, serpentine, and biotitic and pyroxenic porphyrite.

(2) Isolated masses of gabbro, peridotite and lherzolite, granite, syenite, and porphyry.

The coarse-grained gabbro and the peridotitic masses together with those of granite and syenite, associated with minute gneiss and mica-schist, are prevalent more especially in the hills between Lanzo and Ivrea, where a number of interesting, mostly quarried exposures occur at Balangero, Corio, Levone, Rivara, Cuorgné, Belmonte, Locana, Vidracco, Castellamonte, Baldiserro, Muriaglio, Lessolo, and Traversella, in and between the Malone, Orco, and Chiusella Valleys at levels from 400 to 800 metres altitude. Extensive masses of granite and syenite also crop out north of Biella in the Cervo Valley, while east of Biella to Val Sesia and Lake Orta runs, parallel to the diorite belt, a continuous belt of grey and reddish granite 2 to 4 kilometres in width, flanked on the south by a large lenticular mass of red porphyry which extends to Borgosesia in the lower Sesia Valley and thence to Lake Maggiore.

The great diorite belt begins near Castellamonte (408 m.) in the Orco Valley, about midway between Ivrea and Lanzo, crosses the Dora Baltea at Ivrea (267 m.), Montalto and Bio, continues north-east to Donato, Ceresito, Graglia, Pollone, and Biella (410 m.), traverses the Cervo Valley at Adorno (600 m.), and thence extends to Val Sesia between Varallo (450 m.), Scopa, and Scopello (650 m.). From Donato, close to the great eastern moraine wall or Serra d'Andrate, the diorite is flanked on the left by serpentine and porphyrite belts, each about 1 kilometre in width, which extend for about 20 kilometres to the Sessera Valley, midway between the Cervo and Sesia Valleys.

[1] The eclogitic mica-schist formation with pietre verdi has revealed a considerable variety of jadeitic and jadeitoid rocks which S. Franchi, V. Novarese, and A. Stella discovered both in nodules and blocks in situ and as pebbles in the alluvia of rivers in various parts of the Piedmontese Alps. These eclogitic and chlorito-melanitic rocks correspond with the Neolithic implements of Piedmont, thus proving the latter to be, not exotic, but indigenous. "Nuovi Giacimenti roccie giadetiche": Boll. R. Com. geol., 1900, p. 119; Boll. Soc. geol. ital., 1903, pp. 130, 135, 141.

In all these isolated or continuous masses of basic and acid eruptive rocks the structure is prevalently massive and granitoid, rarely schistose, with essentially primitive elements without alteration by metamorphism. Peridotite and lherzolite are much more in evidence than the altered product serpentine. The granite with white and pink felspar, very little mica, but rich in quartz, is made up of smaller elements than ordinary granite. Both it and the syenite masses of Traversella and Biella are closely related to the diorite which at Pollone, near Biella, becomes micaceous, then quartzose, and then passes into granite. The greenish-grey granitoid diorite with hornblende and biotite, often garnetiferous, is essentially massive and unaltered ; only in contact with peridotite or gabbro is there an occasional tendency to prasinitic alteration by decomposition, but without contact metamorphism. The diorite and porphyrite beds, although running parallel for 20 kilometres, are nowhere in direct contact, but always separated by a band of serpentine, mica-schist, or sericitic, quartziferous schist. The porphyrite (Gastaldi's melaphyre) contains occasionally, e.g. near the Oropa Sanctuary above Biella, lenticular blocks of mica-schist, the former thus having probably consolidated somewhat later than the latter. The sericitic, quartziferous schist is of the same greywacke type as that flanking the diorite belt of Gran Nomenon and of Val Cogne in the Aosta Valley. Between those two diorite belts, linked by the intermediate diorite mass of Locana in the Orco Valley, there is, as already mentioned, obviously a zonal connexion. The locality of Locana is also remarkable for its considerable outcrop of greyish-green lherzolite—a bank 300 metres in depth—which rock Baretti [1] found to be composed of 75 per cent of olivine and 25 per cent of greyish-yellow enstatite and green diopside.

As previously mentioned, the Ivrea diorite belt reaches north-east to the upper Sesia Valley above Varallo, where it becomes schistose and gives place to the so-called Sesia gneiss which, further east, in the Strona Valley north-west of Lake Orta, takes the name of Strona gneiss. Both gneisses are of the kinzigitic type already described, the Sesia variety being rich, the Strona variety poor in mica. The apparently abrupt cut-off of the diorite in Val Sesia was formerly regarded as evidence of a great hiatus due to a fracture fault ; in reality, however, the diorite has its sequel between the Sermenza and Mastellone Valleys north and north-west of Varallo, where the kinzigitic gneiss is largely developed in its schistose form, associated with gneissiform, schistose, diorite, norite, gabbro, and peridotite. The gneissic sedimentary rocks, known as stronalites,[2] are frequently intercalated in the eruptive series and vice versa. This high-level

[1] M. Baretti, "Studi Gruppo Gran Paradiso" : Mem. Acc. Lincei, Torino, 1876, p. 195 et seq.

[2] The rocks of the Val Sesia and Val Strona region are described in detail in R. E. Artini and G. Melzi's "Ricerche petrogr. e geol. Val Sesia" : Memoire in Ist. Lomb., xviii, p. 219 et seq., Milano, 1900.

complex, reaching up to 2,500 metres altitude and including the schists of Fobello and Rimella, constitutes Gerlach's second, separate, upper dioritic zone; but, as Franchi and Novarese [1] have shown, it forms an integral part of the entire Lanzo–Ivrea–Verbano (Lake Maggiore) dioritic-kinzigitic area. A branch of the kinzigitic gneissic schist extends from the upper Sesia Valley west by Val Vagno and Croce Rossa into the upper Gressoney Valley, and thence connects with the eclogitic mica-schist of Val Pellina. In Val Sesia the mica-schist extends from Varallo down the valley, and is succeeded by the transverse granite belt, and then by the great porphyry mass of Borgosesia already mentioned.[2] It is a noteworthy feature that the Lanzo–Ivrea–Sesia zone descends to the very edge of the Po Plain, whereas along the western ridge of Lake Maggiore and beyond the kindred rocks are only found at high levels, the general direction of dip being thus north-east to south-west.

Stratigraphically the whole Ivrea–Val Sesia area within the Piedmontese Alps presents the important phenomenon that all the eruptive masses are infolded in the mica-schist and gneiss formation conformably with the latter without any evidence of angular intrusion. This close association and relationship points to the entire crystalline, viz. both the sedimentary and the eruptive, series being of the same age, that is, Permo-Carboniferous. Lithologically, it is noteworthy that while the eruptive series includes every conceivable combination of felspar, quartz, and mica as primitive elements, the only rock conspicuous by its absence is diabase, probably because it associates more readily with the more highly magnesian calc-schist than with the mica-schist and gneiss formation.

It is, of course, quite impossible within the limits of this paper to describe in detail the outcrops in the numerous localities between the terminal points of Lanzo and Val Sesia. Suffice it therefore to state that from Lanzo to Ivrea and Biella the general vertical sequence is, in ascending order, mica-schists and eruptive rocks overlain by subordinate and isolated masses of indubitably Middle Trias crystalline limestone, while from Biella to Val Sesia the sequence is essentially one of juxta- instead of superposition. Of this superficial sequence the most typical example is the section, about 12 kilometres in length, along the Cervo Valley from Montesinaro to Andorno above Biella, which is shown in Fig. 4, and includes the whole eruptive series of old parallel lava streams infolded in the mica-schist formation. It was first pointed out by Gastaldi as early as 1871,[3] and cutting, as it does, right across the crystalline area, is still

[1] Op. cit., 1905, 1906.

[2] There is apparently no passage from the granite to the porphyry or vice versa, but Franchi found (op. cit., 1906) a vein of porphyry in the granite mass, pointing to a somewhat later stage of eruption of the former within the same geological period.

[3] Gastaldi, "Studi geol. Alpi Occid.": Boll. R. Com. geol., 1871, p. 3 et seq., p. 17.

the most extensive and instructive, as it is also the most easily accessible section of the whole region.

Conclusions.

The description given in this and the preceding papers of the six principal crystalline rock-areas of the Piedmontese Alps, condensed and summarized though it necessarily is, will, I think, convey an adequate idea of the eminently characteristic geological and petrological features of each group. Though unique in their collective variety, they reveal a certain uniformity of phenomena which from my own observations leads to the following conclusions :—

1. The pietre verdi, primitive and secondary, appear at all levels from the valley floors of 400 to the highest points 4,000 metres in altitude. Except the prevalence of pietre verdi with primitive elements in the minute gneiss and mica-schist, and of those with secondary elements in the calc-schist formation, there is no order of succession, superposition, or distribution.

2. The basic pietre verdi of all the areas, as well as the acid rocks of the Ivrea belt, are of eruptive origin, but not generally intrusive in the calc-schist and mica-schist formations. They appear in the latter not as irruptive, or as angular injections with apophyses, but as intercalated, lenticular, alternating, and concordantly stratiform planes and masses which sometimes produce the effect of pseudo-intrusive phenomena. There are frequent passages between the eruptive rocks, and from them to the sedimentary rocks and vice versa ; but there is no reliable or conclusive evidence of contact metamorphism.

3. The close association of rocks of different origin is in the first instance the result of repeated compenetration of eruptive viscid masses and of sedimentary deposits in course of consolidation. After the resultant formation of conformable, alternating, interstratified planes as a submarine process of long duration, the rocks thus associated passed through the second phase of being raised and folded simultaneously during repeated earth-movements. The eruptive rocks of the Piedmontese Alps are therefore of the same age as the infolding calc-schist and mica-schist formations respectively.

4. The process of pressure-heat- and hydro-metamorphism of both the sedimentary and eruptive rocks, already in progress before their emergence, continued not only during the repeated periods of raising and folding, but during the repeated Pliocene and Pleistocene glaciations under the long-continued, superincumbent, and shearing pressure of the ice, and the hydrating, decomposing action of percolating water, together with infiltrations from the Pliocene sea of the Po Valley. The dissolving action of the water thus imprisoned and circulating was intensified by the high temperature which it took from the rocks, in conjunction with thermal, highly magnesian springs at various depths.

5. The formation of different groups and combinations of basic and acid rocks out of the submarine, viscid, heterogeneous magma slowly welling up from the reservoirs of molten material in the centres of eruption, took place according to chemical and mineralogical affinities, the basic material separating out, grouping, and crystallizing more rapidly, the acid more slowly. Hence the basic rocks of the Ivrea belt were probably consolidated at a somewhat earlier stage than the acid rocks, but within the same geological period.

6. The transformation of the pietre verdi with primitive to those with secondary elements is the combined result of metamorphism and of decomposition by hydration which led to the modification and reformation of the decomposed elements to secondary groups and combinations. This process is much less in evidence in the pietre verdi of the older or mica-schist than in those of the younger or calc-schist formation, the mica-schist being much less permeable and magnesian than the calc-schist. The transformation probably took place in many cases during the initial stage of consolidation after the eruption of a highly magnesian magma in the calc-schist formation, e.g. in the areas of Monte Viso and the western part of the Lanzo valleys.

7. Chemical and mineralogical affinities produced in some cases basic rocks which, though frequently associated, preserved their separate entities, e.g. the associated but separate belts—originally parallel lava streams—of diorite and porphyrite (melaphyre) of the Ivrea area; or, again, peridotite and gabbro and their derivatives serpentine and euphotide. The frequent veins and dykes of gabbric in peridotitic rocks show that the former compenetrated the latter when these, as the more basic, were already in course of submarine consolidation or alteration. Secondary amphibolites and prasinites are derived not only from diorite and diabase, but very largely, by metamorphism, from gabbro and euphotide which, in common with the other pietre verdi, also decompose readily to serpentinous schist or pseudo-serpentine. The gneissiform, calciferous, and schistose pietre verdi are the result, in some cases, of pressure-metamorphism, e.g. gneissic gabbro, gneissic diorite, etc.; in others of compenetration and metamorphism of sedimentary and eruptive material from tuffs and muds, e.g. diabasic and porphyric schists, or in relation to calciferous rocks, amphibolic and pyroxenic "calcefiri" and serpentinous "ophicalce".

8. The principal earth-movements experienced by the Piedmontese Alps after their emergence came from the south-east, viz. from the Mediterranean and the Po Valley, as is shown by the precipitous and greatly folded flanks of the Maritime and Eastern Cottian and Grajan Alps which, together with the Lanzo–Ivrea–Val Sesia area, formed a coastal region contiguous to the Po Valley. Another intermediate movement proceeded from the west and corrugated the great synclinal calc-schist formation. The principal fracture-

faults of the Piedmontese Alps are : (*a*) in the south, the transverse faults of the Stura di Cuneo and of the Col di Tenda and Vermenagna Valleys, along the north-western and eastern bases of the Argentera massif ; (*b*) in the north, the transverse fault along the Dora Baltea Valley ; and (*c*) the great longitudinal subsidence zone south to north along the eastern margin of the Maira-Dora massif contiguous to the Po Valley. This subsidence or flexure zone, bordering on the Pliocene sea, probably extended along the base of the Lanzo–Ivrea–Val Sesia area and thence to the region of the lakes, thus constituting the zonal flexure or settling zone consequent upon the raising of the Alps in Eocene–Miocene times.[1]

Such is, in my view, the consecutive operation of causes and effects which produced the phenomenal masses and groups of eruptive rocks, their intimate association with the crystalline sedimentary formations, and the alignment and configuration of the Piedmontese Alps of the present day. In their infinite variety they offer both geologically and petrologically an inexhaustible field of fruitful and fascinating study, and more especially does this apply to the pietre verdi, which Gastaldi rightly described as the great "magnesian zone", and whose elusive complexity ever reveals new problems without apparent finality.[2]

[1] *Vide* paper No. I of this volume, "The Moraine Walls and Lake Basins of Northern Italy."

[2] The peculiar liability of the whole Italian peninsula to geological changes by eruptive and seismic phenomena, past and present, was aptly emphasized by Professor A. Issel, of Genoa, the late President of the Geological Survey Department. Asked when the geological map of Italy, begun fifty years ago, would be finished, he replied : "like Penelope's web, *never*."

VII.

The Contact-Zone of the Alps and the Apennines in Western Liguria.

I. Introductory.

IN the paper on the Permian formation in the Maritime Alps, etc. (No. II of this volume), I mentioned incidentally that that formation extends from those Alps, viz. from the Montgioie range east into Liguria as far as the Savona Hills. As in the former so also in the latter region, that formation is composed of essentially gneissic schists known as apenninites or besimaudites belonging to the Lower Permian or Permo-Carboniferous, and of sericitic schists, quartzites, and clastic rocks or "anagenites" which constitute the Upper Permian or Verrucano proper, forming a transition to the Lower Trias.[1] The geological limit of the Permian in the Savona Hills coincides more or less with the geographical line of division of the Alps and Apennines at the Colle or saddle—also called Bocchetta d'Altare; but another geological line of division exists still further east, at the junction of the Triassic and Eocene formations in the Chiaravagna Valley near Sestri Ponente, immediately west of Genoa. In reality the geological division is marked, not by either of those lines, but by a contact-zone between them. This contact-zone occupies the whole of Western Liguria and comprises two distinct and dissimilar parts: one, the Triassic calc-schist and pietre verdi area or Voltri group, which extends for about 25 kilometres along the Riviera littoral west of Genoa from Sestri Ponente to Voltri, Varazze, and Celle Ligure, and the other or Savona group, which skirts the littoral for about 15 kilometres from Celle to Savona and Zinola, and is composed for the greater part of a crystalline massif of granitic, gneissic, and amphibolic rocks.

Both these self-contained groups present respectively geological features entirely different from those of the adjacent areas east and west. Having examined them both some years ago, I propose to confine the present paper to the crystalline massif of Savona, which, owing to its altogether abnormal position and composition, is of absorbing interest, and has within recent years been the subject of remarkable interpretations as an overthrust complex *par excellence*. The Voltri group I propose to consider in a future paper in connexion with the adjoining ophiolithic area of Eastern Liguria.

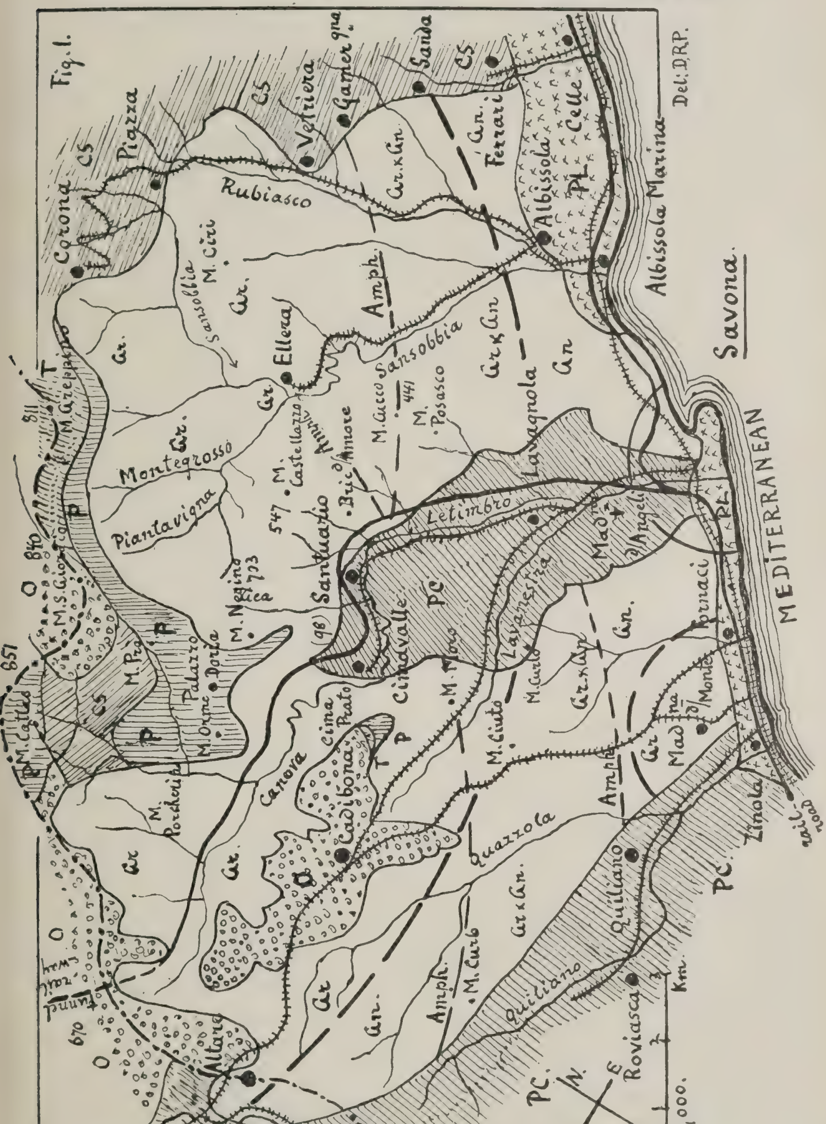
II. General Features. (Fig. 1.)

The Savona Hills form approximately a rectangular area about 15 and 10 kilometres in length and width or 150 square kilometres,

[1] This division has its exact equivalents in the Apuan Alps or Carrara Mountains as the lowest formation underlying the marmiferous Trias, and in the Verrucano—a name derived from Monte Verruca—of the Pisan Hills.

SKETCH-MAP OF CRYSTALLINE MASSIF OF SAVONA.

(Contact-Zone of Alps and Apennines in Western Liguria).



Gr, Gn, Amph.=granitic, gneissic and amphibolic rocks; PC.=Permo-Carboniferous; P.=Permian; CS. × T.=Trias; O.=Oligocene; PL.=Pliocene.

its general direction being south-west to north-east. On the south a rugged, craggy wall of gneiss runs along the coast-line with some intervening Pliocene deposits at Celle, Albissola, Savona, Fornacci, and Zinola. On the west it skirts, from the coast upwards, the Permo-Carboniferous formation to Quiliano, Roviasca, Monte Curlo, and the village of Altare, a commanding point on the divide between Liguria and Piedmont, at about 600 metres altitude. Thence, on the north, it follows the crest-line of the Apennines to Mte. Castlas (851 m.), Mte. San Giorgio (840 m.), and Mte. Greppino (811 m.) to the village of Corona in Triassic and Tertiary strata. On the east, from Corona down to the coast at Celle, the border coincides with the junction line of the calc-schists and pietre verdi of the Voltri group, along which lie the villages of Piazza, Vetriera, Gameragna, Sanda, and Ferrari.

Within this rectangular area the hills rise near the coast to 300 and 400 metres altitude, including Madonna degli Angeli immediately north of Savona, and Madonna del Monte in the south-west corner near Zinola; then in the centre to 500 and 600 metres altitude, notably Mte. Curlo, Mte. Ciuto, Mte. Cucco, and Mte. Castellazzo; and lastly to the crest-line up to 850 metres altitude, including, besides the points already mentioned, Mte. Prà (817 m.) and Mte. Negino (703 m.). The hills are intersected by numerous torrents, generally in deeply eroded ravines, running towards the coast, the principal ones being the Quiliano and Quazzola at the western end, the Letimbro with its affluents the Canova, Gea, and Lavanestra in the centre, and the Sansobbia with its tributaries the Riobasco, Piantavigna, and Montegrosso at the eastern end.

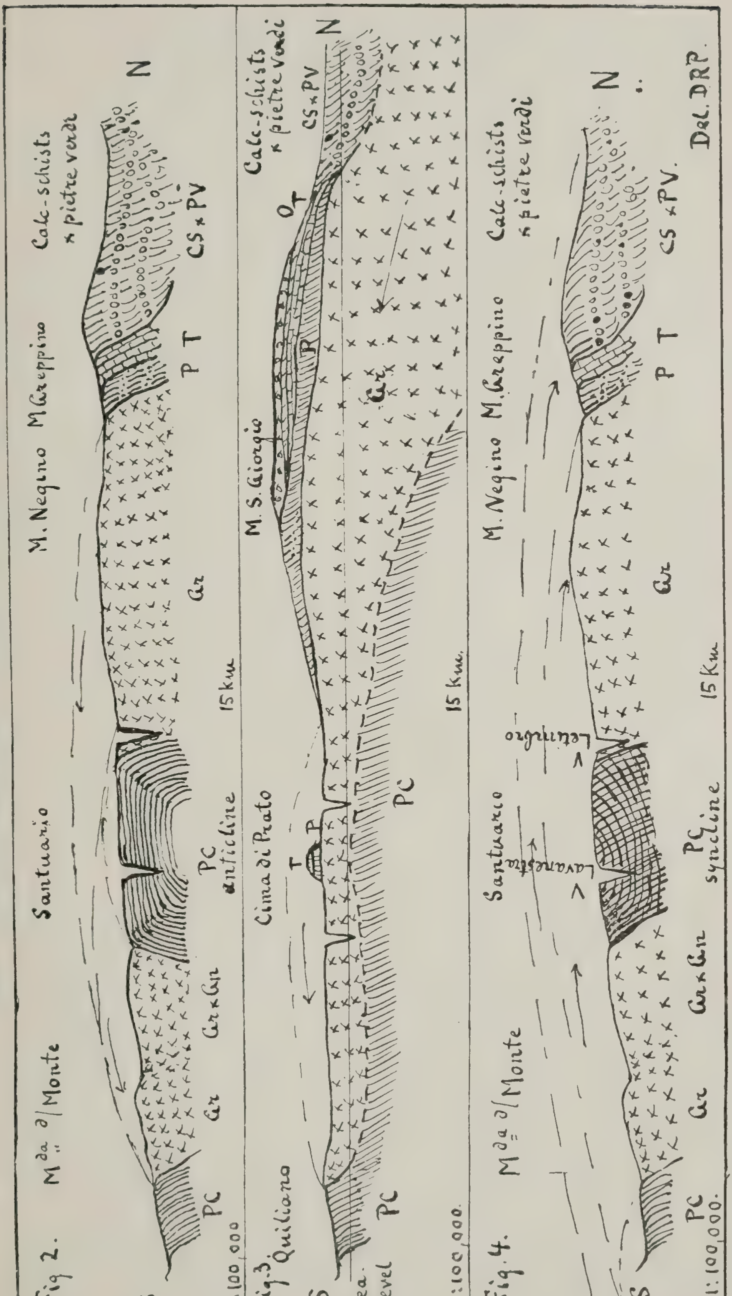
All the localities, points, and ravines mentioned are geologically important for the examination of this extremely complex area, access to which is rendered easy not only by the Savona and Turin railway traversing its central and western part in numerous tunnels and cuttings, but more especially by the roads which run from different points of the Riviera road up into the hills. Among these are the great highway from Savona to Cadibona and Altare into Piedmont, the road to Santuario and Cimavalle in the Letimbro Valley north of Savona; the Quiliano and the Madonna del Monte and Cadibona roads in the western, and those from Albissola to Ellera, to Piazza and Corona, and from Celle to Ferrari in the eastern part of the area. All these roads offer a great variety of interesting and instructive exposures.

III. The Crystalline Massif. (Fig. 1.)

Within the rectangular border-lines of the Permian, Triassic, and Tertiary sedimentary formations, the crystalline massif occupies practically the whole area, with two exceptions. One of these is an island of underlying Permo-Carboniferous gneissic and sericitic schist, about 7 by 4 kilometres in length and width, which stretches

SECTIONS OF CRYSTALLINE MASSIF OF SAVONA, WESTERN LIGURIA.

Fig. 2. Local and partial overthrust E. to W. Fig. 3. Exotic wedge-overthrust of whole massif E. to W.
Fig. 4. Overthrust of whole massif from Maritime Alps W. to E.



PC. = Permo-Carboniferous; Gn. = gneiss; Gr = granite; P. = Permian; T. = Trias; O. = Oligocene.

from Savona and Madonna degli Angeli north-west to Santuario (98 m.). It has obviously been eroded by the Letimbro and Lavanestra torrents which join a few kilometres above Savona and discharge into the sea at that town. The other exception is a wedge of overlying Permian schist, Triassic limestone, calc-schist with pietre verdi, and Oligocene conglomerate which projects from the north near Monte Ormé and Palazzo Doria to within a kilometre of the Permo-Carboniferous island at its upper or Santuario end. The intervening gap thus forms the superficial connecting link between the two fairly equal parts of the crystalline massif. The only other island in the latter is that of Cadibona in the north-western part of the area composed of overlying Oligocene conglomerates and breccia, at whose eastern extremity occurs at Cima di Prato, west of Cimavalle, an extraordinary isolated outcrop of Permo-Carboniferous schist, mica-schist, and gneiss, and Permian schists, surmounted by a cap of Triassic dolomitic limestone.[1]

The anomalous phenomenon which chiefly governs the problem of the Savona region is that the Permo-Carboniferous schists in the south, and more especially those of the Savona and Santuario island, crop out below the crystalline massif, while the Permian and Triassic strata in the north overlie it. The gneissic rocks which occupy the greater part of the southern area are crossed by two bands of amphibolic rocks S.W. to N.E. intimately associated with the gneiss. The whole northern part of the massif, on the other hand, is composed of granitic rocks, which, in the eastern part, are surrounded on the north by a band of Permian schist, and on the south are in contact with gneiss and amphibolic rocks ; in the western part the granitic rocks have the same contact as on the south, while on the west the adjacent formations are Permo-Carboniferous schists and Oligocene conglomerates. Granitic rocks also occur among the gneisses and amphibolites, and form a considerable separate mass near Madonna del Monte, in the south-west corner of the area.

IV. The Crystalline Rocks.

The granite when fresh and unaltered resembles in some respects the Alpine type, is often porphyroid and granulitic in structure, of pale colour, and exhibits as its principal constituents abundant large and medium-sized elements of quartz, plagioclase, considerably or wholly kaolinized, with some orthoclase and subordinate black biotite and muscovite. In a small isolated mass in the north near Pian di Burré, about 500 metres altitude, it is more fine-grained and in part microgranitic. The granitic rocks, both in their fresh, unaltered, and in their far more often altered and friable condition, are well exposed along the Savona and Turin railway in the Upper Letimbro Valley, in the ravines of the tributary torrents Canova and

[1] This outcrop was pointed out by G. Rovereto in a memoir to be quoted later. The small dolomitic cap is obviously a local overthrust from the larger deposits further north-east.

Porcheria, and in Monte Porcheria in the western part of the area. In the eastern part interesting outcrops occur in the eastern flank of Monte Negino, in the Piantavigna and Montegrosso ravines, and notably in the Sansobbia Valley near Ellera, in Monte Ciri, between the Sansobbia and Rubiasco Valleys, and in the latter valley between Piazza and Vetriera along the road from Albissola to Stella.

The gneiss when unaltered is rich in dark brown or black biotite with muscovite, and exhibits large orthoclase and plagioclase elements together with granular quartz. It differs from the Permo-Carboniferous gneiss chiefly in that the latter is more fine-grained, with more muscovite, and paler in colour ; but the differentiation is often very difficult.[1] Interesting outcrops of gneiss with associated minute gneiss and mica-schist are those along the coast between Albissola and Savona, where the gneiss is perhaps more unaltered than in other parts of the area ; along the Savona and Altare road, in the Lavanestra Valley, where gneisses, amphibolites, and granite alternate ; also on the road from Celle to Ferrari and Sanda, on the eastern margin of the area, where the gneiss is in contact with calc-schist and pietre verdi, and in the south-west in the Quazzola Valley and on Monte Ciuto.

The amphibolites are largely derived from pyroxenic rocks with uralitized augite and saussuritized felspar, so much so that often hardly, if any, trace is left of the original constituents. They are closely associated with the gneissic rocks, and differ from the pietre verdi of the calc-schist horizon on the northern and eastern border as much as the corresponding rocks of the Piedmontese Alps. Of the two bands which cross the gneissic masses from south-west to north-east the larger one may be traced from the Quazzola Valley to a point where it traverses the road between Monte Ciuto and Cadibona, and then the Savona and Altare road near Monte Moro in the Lavanestra Valley ; thence, on the eastern side of the Santuario island to Bric dell'Amore, Monte Cucco, and the Albissola and Ellera road in the Sansobbia Valley. The lesser, more southern band, in contact with the granitic mass of the Madonna del Monte, crosses the road from the latter point to Cadibona south of Monte Ciuto. Some of the best exposures of the principal band occur on the ridge from Savona north to Crocetta, and towards Monte Negino, where the amphibolic banks, notably in Monte Pasasco and north of Monte Cucco, reach a thickness of over 400 metres.

Between the granitic, gneissic, and amphibolic rocks as the principal constituents of the massif, there are countless passages ; all the rocks with rare exceptions exhibit more or less marked evidence of alteration, crushing, and lamination, and intense, often vertical

[1] The Permo-Carboniferous gneiss is largely developed in the Quiliano and Roviasca Valleys, in the Bormida Valley west of Altare, and further north-west down to Ferrania di Mare in the same valley ; also along the Lavanestra Valley in the Savona and Santuario island.

folding, in striking unconformity with the subjacent Permo-Carboniferous and the overlying younger sedimentary formations.

The sedimentary formations comprise, in ascending order, the Permo-Carboniferous gneisses, mica-schists, and the dark, dull sericitic, often green chloritic schists known as phyllades or *schisti plumbei*; the paler Permo-Triassic sericitic schists, quartzites, and clastic Verrucano, including also the lustrous and varicoloured grey, green, and violet *schisti rasati* [1]; and the Triassic dolomitic and fossiliferous, tegular, micaceous, and black limestones, the latter corresponding to the grezzoni of the Apuan Alps and belonging to the Middle Trias. These are overlain by the Upper Trias calc-schists with pietre verdi. The extensive deposits of Oligocene fossiliferous conglomerates and breccia on the crest-line and on the flanks of the hills below that line are an important factor as evidence of a marine formation on the former, subsequently raised littoral.

V. The Problem of Age, Structure, and Origin.

This problem has been fruitful of various, often directly opposed interpretations ever since 1841. Sismonda and Pareto regarded the crystalline rocks as primitive and protogine; Gastaldi classed them, including the apenninites, so called by him, as Upper Archæan, though more recent than his calc-mica schist and pietre verdi zone. Zaccagna,[2] and with him Issel and Mazzuoli,[3] in 1887 included the whole crystalline Savona series in the Permo-Carboniferous and Permian horizon of the adjoining Maritime Alps, while De Stefani,[4] in the same year, maintained Gastaldi's view of the Pre-Palæozoic uniformity of all the crystalline rocks of the Western Alps and Liguria.

Since then the most important investigations of the Savona region have been those of Franchi (1893), Rovereto (1895 and 1909), and Termier and Boussac (1911–13), followed by the dissentient views of De Stefani (1913), who confirms his previous ones already mentioned, and considers the Savona massif formed in situ.

1. Franchi, in a valuable memoir,[5] vindicating Pareto's protoginic view, considered the gneissic, amphibolic, and granitic masses as constituting a crystalline massif older than the Permo-Carboniferous

[1] Rovereto assigns these varicoloured *schisti rasati* to the Middle Trias, but they are, as Termier and Boussac also point out, really Upper Permian.

[2] D. Zaccagna, "Costituzione Alpi Marittime": Boll. R. Com. geol., 1884, p. 167 et seq.; "Geologia Alpi Occid.": ibid., 1887, p. 346 et seq.

[3] A. Issel, L. Mazzuoli, & D. Zaccagna, Carta geol. Riviere Ligure, 1887 and 1890.

[4] C. De Stefani, "L'Apennino fra Colle d'Altare e la Polcevera": Boll. R. Com. geol., 1887, fasc. 3; "Zona Serpentinosa della Liguria Occid.": Atti R. Accad. Lincei, Roma, 1913, pp. 547, 661.

[5] S. Franchi, "Nota preliminare formazione gneissica e sulle roccie granitiche del Massiccio Ligure": Boll. R. Com. geol., 1893, p. 43 et seq. In this memoir Franchi also describes the principal rocks microscopically and gives a list of the literature 1841 to 1893.

and all the other formations of the district. The gneisses and amphibolites he regarded as primitive and the granite as intrusive in, and therefore more recent than, the same. The superposition of the gneiss on the Permo-Carboniferous near Quiliano in the south-west corner of the area is, in his view, due to an inverted fold (*rovesciamento*), the normal sequence of gneiss and Verrucano appearing further north, near Altare. He regards the Savona crystalline massif as forming part of the inner Alpine belt of massifs from Monte Rosa to the Grajan, Eastern Cottian, and Maritime Alps, and the Savona gneisses as akin to those of Gran Paradiso and La Levanna (Grajan Alps) rather than to those of Mont Blanc.

2. Under a novel aspect the problem was presented in an important memoir with maps and sections by Rovereto in 1909.[1] His painstaking survey of both the crystalline and sedimentary formations of the area led him to the conclusion that the reversed, anomalous sequence of the gneiss and the Permo-Carboniferous series is best explained by a local and partial overthrust or displacement of gneissic and granitic rocks from the eastern to the western part of the area. This conclusion he bases on the following grounds :—

(1) That the Permo-Carboniferous island between Savona and Santuario presents all the characteristic features of a "window" which discloses that formation as the substratum, here assumed to form an anticline.

(2) That in the south-western part of the massif the gneiss mass, to which the Permo-Carboniferous strata are adjacent on either side, rests against the latter obliquely in opposite directions, and is therefore fan-shaped,[2] whereas the gneiss mass north-east of the Santuario island is essentially isoclinal.

(3) That in that island the eastern contact line of the Permo-Carboniferous schists and the gneiss is comparatively normal and undisturbed, whilst the western contact line exhibits marked unconformity, contortions, and brecciation.

Hence the inference that the eastern part of the crystalline massif is a "rooted" and the western part a "transported" area, viz. a cover-sheet by displacement.[3] The gneisses and amphibolic rocks of the massif are, according to Rovereto, Pre-Carboniferous, and the granite erupted in the Upper Palæozoic.[4]

[1] G. Rovereto, "Zona dei Ricoprimenti del Savonese" : Boll. Soc. geol. It., 1909, p. 389 et seq. This memoir was preceded by two preliminary notes on the same subject in 1895.

[2] This fan-structure, shown in general section Fig. 2, rests on the assumption that the adjoining Permo-Carboniferous island on the right is an anticline, not a syncline.

[3] Besides this solution Rovereto adumbrates three others, which, however, he considers less tangible : the first assumes the whole massif to be a rooted, the second a transported area, and the third assumes not only the Savona area but the whole of the Apennines to be a series of transported cover-sheets.

[4] Franchi (op. cit., p. 64) refers to the granite as being on the eastern border intrusive also in the calc-schists and pietre verdi ; these being Mesozoic, the granite would be much younger than Upper Palæozoic.

3. A much bolder and sweeping interpretation of the Savona massif is that of Termier and Boussac in their brilliant memoir of 1912.[1] Discarding Rovereto's local and partial overthrust as too timid, incomplete, and wanting in precision, they argue with characteristic *entrain* and incisive style and treatment in favour of a comprehensive overthrust of exotic, long distance origin, and from that point of view the subject is worked out so thoroughly that it will be interesting to outline its salient points.

(1) The extensive examination of the area by the authors leads them to extol the Savona crystalline massif as an ideal " cover-sheet " region, which, in point of transport and overthrust phenomena, they consider the most typical, unique, and classic of its kind in Europe. All along the roads, in the ravines, and on the heights they find in the abundant examples of intense crushing, lamination, brecciation, and friability of the crystalline masses conclusive evidence that these masses were, by subterraneous transport from an exotic source, wedged between the two sedimentary—the Permo-Carboniferous and the Triassic—formation of the Savona Hills, and thus became the dividing and contact-zone between the Alps and the Apennines.

(2) While wholly adopting Rovereto's view of the Savona and Santuario Permo-Carboniferous " window ", the authors dissent from his lithological distribution of the crystalline rocks, and regard the massif as in the main composed of granitic, and only to a very minor extent of gneissic and amphibolic rocks, the proportion of the three being, according to their estimate, respectively $\frac{2}{3}$, $\frac{1}{6}$, and $\frac{1}{6}$.[2] In this estimate they also include a good deal of Permian schist which they regard as altered granitic rock. Of the enormously predominant granitic masses, as also of the gneisses and amphibolic rocks, only a small part is intact and unaltered ; the great bulk is altered, structurally and mineralogically, to mylonites, viz. bruised, crushed, laminated, mashed, and brecciated by friction of transport and by dynamic pressure.

(3) The granite when fresh contains 68 per cent of silica and in chemical composition comes near to that of Mont Blanc, but nearer to that of Elba, where Termier already previously claimed extensive granite areas as mylonites,[3] which he correlates with, and quotes in support of the phenomena in the Savona region. Of the mylonitic granite the authors enumerate seven varieties or stages between

[1] P. Termier and J. Boussac, " Le Massif Crystallin Ligure " : Bull. Soc. géol. France, 1912, p. 272 et seq., with map and 2 sections, preceded by two preliminary notes of 1911.

[2] Rovereto's distribution of granite, gneiss, and amphibolites may be estimated from his map as $\frac{3}{10}$, $\frac{6}{10}$, and $\frac{1}{10}$ respectively, his granite area being less than half that of Termier and Boussac.

[3] P. Termier, " Tectonique de l'Ile d'Elbe " : Bull. Soc. géol. France, 1910, p. 314 et seq. The conclusions of this memoir were contested by B. Lotti, " L'ipotesi del Termier sulla tettonica Isola d'Elba " : Boll. R. Com. geol., 1910, p. 284 et seq. ; and by V. Novarese, " Il presunto piano mylonitico dell'Isola d'Elba " : ibid., 1910, p. 292 et seq.

fresh unaltered granite and the most advanced mylonitic rock as the other extreme. The first four stages comprise the fissured and brecciform, the partially crushed and laminated, the intensely laminated, and the incompletely crushed but not laminated rocks, while the last three represent the most advanced types of mylonitization, the rocks being reduced to a trachytic, phonolitic, and, as the last stage, to a talcose aspect, completely mashed and laminated, no minerals being microscopically recognizable. These rocks occur more especially along the friction surfaces of the massif. The seven varieties may be studied along the roads leading from the coast into the hills, and notably along the paths leading from Savona up to Monte Negino in the central part of the area.

4. The cataclastic structure and chaotic condition of the crystalline rocks are, in the authors' view, dominant features in favour of the massif being an overthrust *en bloc*. The striking unconformity, often at right angles, between the massif and the underlying and overlying formations, and its wedge-like form, thinning out from 1,000 metres in thickness in the centre to 200 metres at its north-western end, viz. in the direction of thrust, afford evidence not of a merely local and partial displacement but of the exotic origin of the entire massif.

5. The upper transport and friction surface of the massif is, in the authors' view, evidenced by the extremely disturbed and brecciated condition of the overlying younger formations in contact with the crystalline rocks. While the upper surface thus forced itself below those formations, the lower surface glided, like a *traîneau écraseur*, along the gently undulating surface of the " fixed " Permo-Carboniferous substratum. Thus the Savona massif was, in the authors' view, transported subterraneously, in a *fuite prodigieuse* (*sic*) from the east, its rooted origin being, in common with the granite massifs of Eastern Corsica and Elba, in the Dinarides.[1]

The two parallel sections south to north, Figs. 2 and 3, illustrate respectively Rovereto's and Termier and Boussac's overthrust interpretations ; Fig. 4 represents an alternative interpretation explained at the end of this paper. The sketch-map, Fig. 1, gives, in dotted lines, the approximate zonal direction and distribution of the crystalline rocks ; but the countless passages of the three principal rocks preclude any clear definition of limits.

VI. Conclusion.

Without in the least disparaging the overthrust theory *per se*, which in specific cases offers the only tangible explanation of stratigraphical anomalies, it may, in my opinion, be safely averred that as regards the Savona massif, all the individual and collective phenomena so

[1] The theory of the Dinarides being the rooted origin of the three granitic areas is founded on G. Steinmann's often-quoted memoir, " Alpen und Apennin " : Monatsber. Deutsche Geol. Ges., 1907, p. 177 et seq. ; his " dinaric cover-sheets ", however, are assumed to have been transported, not direct from east to west, but circuitously along the curve-line of the Alps.

ably marshalled by Rovereto and Termier and Boussac lend themselves with equal, perhaps greater force to a more natural and rational interpretation.

The Savona region, whose crest-line at Mte. Castlas, Mte. S. Giorgio, and Mte. Greppino lies at about 825 metres altitude, forms a depression between Mte. Settepani (1,391 m.) in the Maritime Alps on the west and Mte. Ermetta (1,267 m.) in the Voltri Apennines on the east. The depression of 500 metres thus constitutes a syncline, in the centre of which the region is deeply cut from north to south, and in its lower part, between Santuario and Savona, is eroded to a width of 4 kilometres by the Letimbro and Lavanestra. In striking contrast to the regularly stratified and undisturbed slopes on the north or Po side of the Apennines, the Savona region is intensely folded, contorted, and faulted, the maximum of disturbance being in the centre, viz. in and near the Letimbro Valley immediately west and north of Santuario, where all the rock formations converge.

As previously mentioned, the northern part of the region is largely covered, in places to a depth of 400 metres, by Oligocene marine conglomerates and breccia which represent a former littoral formation raised in later Oligocene or early Miocene times. It was during that emergence and raising from the sea that the Savona region was, by enormous pressure from below and from both sides west and east, compressed, folded, fractured, brecciated, and, as Termier and Boussac term it, reduced to a chaotic condition, a process repeated on a smaller scale in Post-Pliocene times and followed in each case by a settling which gradually produced the present depression and contact-zone between the Alps and the Apennines.[1]

This enormous compression by repeated earth-movements explains the crushing, lamination, brecciation, and more or less intense alteration of the crystalline rocks, as well as the highly angular unconformity between them and the sedimentary formations, and the marked disturbance of the latter along the lines of contact. The many passages and stages of alteration in the crystalline rocks render a differentiation between transformed granite, gneiss, and amphibolite very difficult ; but the granite rocks being largely predominant and of eruptive origin, it is by no means improbable that the gneissic and amphibolic rocks too are derived from granite which thus constituted the whole original massif.[2] Its eruption and spreading out over the Permo-Carboniferous formation probably took place in

[1] L. Mazzuoli, in an interesting memoir on the "Formazione dei Conglomerati Miocenici nell'Apennino Ligure", Boll. R. Com. geol., 1888, p. 9 et seq., mentions the noteworthy fact that soundings carried out by the Italian Marine Department along the Riviera littoral of Genoa and Savona have proved the existence of submarine river valleys at depths up to 900 metres at 4 nautical miles from the shore. The ratio of fall below sea-level is thus about the same as that from the Apennine crest-line to the coast.

[2] The gneissic rocks of Valdana, in the south-eastern part of Elba, are by common consent of granitic origin, though older than the micrograntes in the west of Elba (B. Lotti, op. cit., p. 285).

early Miocene times, i.e. contemporaneously with the great granitic injections in Elba, as well as in the Argentera and Gran Paradiso massifs of the Piedmontese Alps. This interpretation thus solves without an overthrust the cardinal problem of the abnormal superposition of the crystalline rocks on the Permo-Carboniferous formation.[1]

If, on the other hand, the problem is to be solved by an overthrust, it appears more probable that the whole crystalline massif was transported, not from the east, but from a much nearer root in the west, that is, from the Argentera gneiss and granite massif in the Maritime Alps, whence it "glided" over the intervening Permo-Carboniferous formation of the Montgioie range to its present position probably in Mid-Tertiary times.[2] The overlying Verrucano, Triassic limestones, and calc-schists with pietre verdi were, in that case, similarly transported from the Montgioie range, probably in the same geological period, the calc-schists being pushed beyond the Savona massif as a cover-sheet forming the present abnormally located Voltri group.[3] This alternative overthrust is indicated in the section Fig. 4.

The interpretation of an overthrust is alluring, but of necessity hypothetical. It has been truly remarked that there is no difficulty, obstacle, or objection which the overthrust theory cannot overcome by geometrical designs.[4] Rovereto himself calls it *geopoetismo*.[5] When, therefore, a stratigraphical problem admits of a more tangible and legitimate in situ explanation, the presumption and balance should logically be in favour of the latter, and this may reasonably apply to a region geologically so singular and attractive as that of the contact-zone of Savona.[6]

[1] By this interpretation Termier and Boussac's exotic granite mass, section Fig. 3, whose submarine part is of course purely hypothetical, becomes simply an ordinary intrusive mass formed in situ. According to G. Steinmann (Geol. Congress Francfort o/M., 1913) the Tertiary granitic intrusions constituted the last orogenetic phase of the Alps and Apennines.

[2] The Permo-Carboniferous "window" would in that case be a syncline, and the adjacent crystalline mass west would be, not fan-shaped, but isoclinal.

[3] Termier and Boussac themselves assume the younger formations to have moved as cover-sheets from west to east, viz. in the opposite direction of the crystalline massif.

[4] V. Novarese, "Il Profilo della Grivola, Alpi Graje": Bull. R. Com. geol., 1909, p. 497 et seq.

[5] Op. cit., p. 408.

[6] It is only since this paper was reprinted that Professor T. Taramelli's three notes *contra* the theory of exotic overthrusts or *carreggiamenti* in the Apennines and Alps (Rend. Ist. lomb., 1913, p. 128, p. 390, p. 1009) have come to my notice. His views fully agree with mine that the Savona crystalline massif was formed essentially in situ and is not derived by transport from the Dinarides.

VIII.

The Ophiolithic Groups of the Ligurian Apennines. Western Liguria.

THE groups of ophiolithic, that is, crystalline ferro-magnesian rocks in the comprehensive sense, to be dealt with in this and the subsequent paper are those west and east of Genoa.[1] Of these the principal western or Voltri group was already referred to in the preceding paper [2] as being, on its western margin, contiguous to the crystalline massif of Savona, and as constituting with the latter the geological contact-zone of the Alps and the Apennines. The anomaly of its position and petrological character is enhanced by the abrupt, clean-cut division of its eastern margin from the adjacent, more recent, and smaller ophiolithic group of Sestri and Isoverde, which is coeval with the groups of Eastern Liguria.

The Groups of Western Liguria. (Fig. 1.)

The border of the large and important area known as the Voltri group runs on the south, from its contact with the Savona massif near Varazze, along the Rivieria to Cogoleto, Arenzano, Voltri, Prà, Pegli, and Sestri Ponente ; then north up the Chiaravagna Valley, to Isoverde in the Iso Valley, to the Bocchetta Pass on the crest of the Apennines, and thence to Voltaggio in the Lemmo Valley. From here it extends, as the northern margin, across the Corrente, Stura, Orba, and Erro Valleys to near Ponzone, south of Acqui, whence it turns south to the Giovo Pass and Corona, and along the contact line of the Savona massif down to the coast at Varazze. The divide of the Apennines runs more or less parallel to the coast from the Giovo Pass (522 m.), to Mte. Ermetta (1,262 m.), Mte. Resia (1,184 m.), the Turchino Pass (552 m.), Mte. Penello (996 m.), and the Bocchetta Pass (777 m.), so that only the southern part or about one-third of the area lies in Liguria proper, while the northern and larger part belongs to the Po watershed; in its entirety the complex, covering no less than 36 by 22 km. or 800 square kilometres, is by far the largest in the Apennines. It exceeds even that of the Lanzo Valleys in the Piedmontese Alps ; like the latter it has, owing to its prevalently peridotitic and serpentinous rocks, resisted denudation and hence preserved its compactness, continuity, and also its often austere aspect in a remarkable degree. The three principal roads along which,

[1] The term ophiolithic, though in its original and narrow sense it refers only to serpentines, applies to eruptive basic rocks or pietre verdi comprehensively, irrespective of age, like, e.g., the "roches ofitiques" of the Pyrenees.

[2] No. VII of this volume.

Fig. 1. Sketch Map of Voltri Group, Western Liguria.

C S = calc-schists; P V = pietre verdi; Mio = Miocene.
E S = Eocene Serpentine × diabase; Eo = Eocene sedimentary.

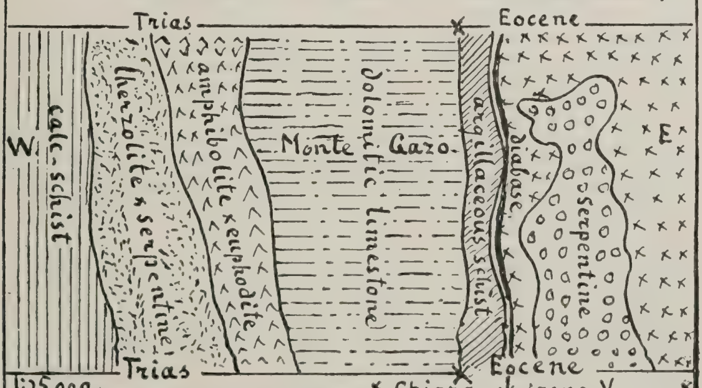


Fig. 2. Contact of Trias and Eocene, Monte Gazo, Chiaravagna Valley.

besides the coast-road, the ophiolithic and sedimentary rocks of the area may be studied, are those crossing the Apennines south to north from Varazze by the Giovo Pass to Sassello and Acqui on the west, from Genoa by the Bocchetta Pass to Voltaggio on the east, and from Voltri by the Turchino Pass to Campoligure, Rossiglione, and Ovada in the centre, to which last-named runs in great part parallel the railway from Genoa to Ovada.

The Voltri group is composed almost entirely of Mesozoic, dark-grey, often talcose calc-schists, and infolded, intercalated, and overlying pietre verdi. As such it belongs geologically to the Alps rather than to the Apennines, and the anomaly of its position consists in its being wedged between the Savona crystalline massif at one end and the Eocene formation at the other. Up to 1882 it was variously assigned to the Archæan, Palæozoic, and, more often, to the Tertiary formations, and it was not till Issel and Mazzuoli's investigations of 1883 and 1884 [1] that a clean-cut line of division was shown to exist north of Sestri in the Chiaravagna Valley, and thence to Isoverde between the older Triassic Voltri group on the western and the more recent Eocene ophiolithic and sedimentary series on the eastern side of that line.

The determining factor in this division was Issel and Mazzuoli's discovery of several isolated deposits of Triassic dolomitic limestone immediately west of the line between Sestri and Isoverde, viz. on Mte. Gazo, Mte. Torbi, and Mte. S. Carlo, and also north of the crest of the Apennines near Voltaggio, while more recently Rovereto [2] elucidated those of Cogoleto and Arenzano on the coast, and Franchi [3] also adduced valuable evidence of the Mesozoic age of the Voltri group. These dark-grey and bluish, cavernous, sparsely fossiliferous (gyroporelle) limestones are, like their equivalents in the Maritime Alps and the Savona region, as also like the grezzoni of the Apuan Alps,[4] indubitably Middle Triassic, underlying normally the Upper Triassic calc-schist and pietre verdi horizon. The three deposits between Sestri and Isoverde present the abnormal phenomenon that they rest on serpentine and amphibolite of that horizon instead of

[1] L. Mazzuoli and A. Issel, " Sovraposizione nella Riviera di Ponente d'una zona ofiolitica eocenica ad una zona ofiolitica paleozoica " : Boll. Soc. ital., 1883, p. 44 et seq. " Zona di coincidenza delle formazioni ofiolitiche eoceniche e triassiche nella Liguria occidentale " : Boll. R. Com. geol., 1884, p. 2 et seq.

[2] G. Rovereto, " Questioni dei calceschisti studiata in Liguria " : Boll. Soc. geol. ital., 1909, p. 408 et seq. " Schisti e serpentine antichi in Liguria " : Atti Soc. Ligure Sc. nat., vol. ii, 4, 1891.

[3] S. Franchi, " Massiccio cristallino ligure " : Boll. R. Com. geol., 1893, p. 43 et seq. " Relazione campagna, 1911 " : ibid., 1912, p. 41. " Posizione della zona a *Helminthoidea labyrinthica* nell'Eocene superiore " : ibid., 1915, p. 297. Franchi claimed the Voltri group as belonging to the Mesozoic calc-schist and pietre verdi horizon of the Maritime and Cottian Alps in " Zona Pietre Verdi, Ellero e Bormida " : ibid., 1906, p. 89 et seq.

[4] Both the Ligurian and the Apuan dolomitic limestone, independently analysed, contains 58 per cent carbonate of lime and 38 per cent carbonate of magnesia.

vice versa.[1] This reversed sequence is, however, purely local and is due to an inverted fold along the greatly disturbed, faulted, and tilted contact of the Triassic and Eocene formations, whose marked unconformity is e.g. well exposed in the Chiaravagna Valley on the eastern flank of Mte. Gazo, as also in the Rio Recreusi ravine on the eastern flank of Mte. S. Carlo near Isoverde. Along the coast near Cogoleto and Arenzano the sequence is normal, the dolomitic limestone and quartzite here being, moreover, as Rovereto has shown, underlain by Lower Triassic quartzite and conglomerate and Permian schist as the substratum. Another curious phenomenon is the wedge of calc-schist, quartzite, and mica-schist which projects from the belt of these rocks on the coast into the pietre verdi area north of Voltri for about 12 kilometres to Mele, the Turchino Pass, and beyond to Masone and Campoligure. This wedge, very similar to the Santuario island in the Savona region, is up to 4 kilometres wide, and divides the Voltri group on the Ligurian side into two unequal parts. Except an outcrop of serpentine in the Stura Valley immediately north of the road-tunnel on the Turchino Pass, it is practically denuded of pietre verdi.

The Eocene formation east of the contact line and thence to the Polcevera Valley, north of Genoa, is composed as usual of fossiliferous (*Helminthoidea*) limestone, argillaceous, often shaly schist, and macigno sandstone. It is in the argillaceous schist between Cornigliano and Sestri, viz. between the Polcevera and Chiaravagna Valleys, that occurs the mass of ophiolithic rocks which extends from the headland of S. Andrea north to Borzoli and Madonna della Guardia for about 8 and 2 kilometres in length and width, while further north several smaller masses crop out at S. Martino, near the Bocchetta Pass, and between the latter and Voltaggio, forming a fringe round the eastern margin of the Voltri group. As in the Savona region, so also in the Voltri area deposits of Oligocene conglomerate and breccia are frequent and extensive, one of the largest being a bank 500 metres in thickness in the Morsone Valley near Voltaggio, which is entirely composed of pietre verdi débris.

The relation of the Voltri group to the adjacent one of Sestri and Isoverde has been the subject of considerable controversy. De Stefani [2] and Termier and Boussac [3] regard the Voltri group as an integral part, not of the Alps, but of the Apennines. In Termier and Boussac's view there is between the two sedimentary and ophiolithic

[1] This superposition Mazzuoli and Issel regarded at the time as normal. They therefore assigned the calc-schist and pietre verdi to the Lower Trias and figured these as such in their map of Liguria of 1887. The formation is now, like that of the Piedmontese Alps, recognized as Upper Triassic.

[2] C. De Stefani, "La zona serpentinosa della Liguria occidentale": Rendiconti Atti R. Acc. Lincei, Roma, 1913, pp. 547 and 661 et seq.

[3] P. Termier and J. Boussac, "Passage latéral N.O. de Gênes de la série cristallophyllienne (schistes lustrés) à la série sédimentaire-ophiolitique de l'Appennin": Comptes Rendus Acc. Sciences, Paris, 1911, p. 1361 et seq.

formations no division or discontinuity, but a gradual passage from Triassic to Post-Triassic, the former being simply more metamorphosed than the latter, and both constituting consecutive series after the pattern of the French Alpine *séries compréhensives*. Sacco assigns the argillaceous schists and the macigno sandstone, including the ophiolithic rocks of the Sestri and Isoverde group, to the Cretaceous, and the uppermost fossiliferous (*Helminthoidea*) limestone strata to the Lower Eocene.[1] The weight of evidence is, however, largely in favour of a distinct difference and division between the two unconformably juxtaposed sedimentary and ophiolithic formations, the Voltri group being Triassic and that of Sestri and Isoverde prevalently Upper and Middle Eocene. The division is shown e.g. in the interesting superficial section of Mte. Gazo in the Chiaravagna Valley (Fig. 2).[2]

The principal constituents of the pietre verdi of the Voltri group are peridotite, lherzolite, serpentine, and euphotidic, amphibolic, eclogitic, and garnetiferous rocks. Although in some cases well preserved, they exhibit more generally various stages of alteration, schistosity, and decomposition, and are, moreover, so interfolded and intermixed both with each other and with the enclosing, often talcose calc-schists that their delimination and subdivision is as difficult as in the similar case of the Lanzo Valleys. The peridotitic and serpentinous rocks alone are easily distinguished by the dark colour, the rugged outlines, and the barrenness of their outcrops, in contrast to the other pietre verdi and the calc-schists often covered with abundant vegetation.

Along the coast-road between Pegli and Prà the headlands exhibit outcrops of dark, dull serpentine and euphotide with glaucophane, in part brecciated and decomposed, alternating with shaly, talcose calc-schist which fringes the coast from Sestri to Voltri.[3] North of Pegli in the Varenna and upper Gorzente Valleys appear lherzolite and serpentine with euphotide veins, and north of Prà, as also north of Voltri, in the Acquasanta ravine, occur considerable rugged outcrops of dark-green and black peridotitic rock, which from their forbidding appearance are known as the Scogli Neri and the Scoglio del Diavolo. Beyond Voltri a large mass of serpentine continues to Arenzano and Cogoleto, where it alternates with peridotitic rock and calc-schist. Between Cogoleto and Varazze a large mass of euphotide stretches north, while at Varazze the dark-green serpentine shows euphotide veins. Thus, the continuous mass of peridotitic and serpentinous

[1] F. Sacco, "L'Age des formations ophiolitiques récentes": Bull. Soc. belge de Géol., vol. v, 1891. *Carta geologica Appennino centrale* 1 : 100,000, Torino, 1891.

[2] This section is deduced from Rovereto's more extensive one, op. cit., p. 414.

[3] Professor Bonney described a few of the coastal rocks between Sestri and Prà in "Notes on some Ligurian and Tuscan Serpentines": Geol. Mag., May, 1879, p. 362 et seq.

rocks, with associated euphotide and alternating with calc-schist along the littoral, is interrupted only by the calc-schist wedge of Voltri and Campoligure previously mentioned.

Along the eastern margin similar outcrops of enstatitic and diopsidic lherzolite, glaucophanic euphotide, and amphibolite appear on the western flank of Mte. Gazo, while further north serpentine predominates west of Mte. Torbi; again, west of Mte. S. Carlo in the Iso Valley a lherzolite mass exhibits euphotide veins, and lherzolite and serpentine also crop out in Mte. Persucco and Mte. Roncasci, west of Caffarella. From here extends on both sides of the Apennine crest the great euphotide mass of Mte. Lecco, probably connected with the similar mass north of Varazze in the south-western part of the area. In this, as in the other euphotide masses, the rock varies from the well-preserved diallagic to the altered type with saussurite and smaragdite, and is often gneissiform, laminated, and schistose. In the Olba Valley, north of the Apennine crest, occur considerable eclogitic masses, and along the western margin contiguous to the crystalline massif of Savona, the pietre verdi, which overlie the latter at Corona, present the usual varieties already mentioned.

Although the Triassic pietre verdi of the Voltri group and the Eocene ophiolithic series are both of eruptive origin, they exhibit certain differences, not of substance, but of facies and degree. Thus, the older serpentines are more uniformly dark and dull in colour, the younger generally a brighter, richer, and more lustrous green, with varicoloured passages; again, the pietre verdi when schistose often pass to the infolding calc-schists, whilst the Eocene rocks are more clearly defined from the sedimentary strata. The former are more often amphibolic, the latter more pyroxenic, viz. diabasic. The serpentino-calcareous rock "ophicalce" is rare in the Voltri group, but not infrequent in the Eocene series, and the same difference applies in an enhanced degree to metalliferous deposits. These differences are clearly exhibited in the Eocene ophiolithic series of Eastern Liguria, as well as in the smaller, essentially serpentinous and diabasic masses infolded in the Eocene sedimentary strata between Sestri and Isoverde and bordering on the eastern margin of the Voltri group. Among these are notably the outcrops of the S. Andrea headland on the coast near Sestri; of S. Rocco, east of Panigara in the Chiaravagna Valley; of Borzoli and of Madonna della Guardia at the northern end of that mass [1]; again, further north, those of Caffarella and S. Martino, which latter village is built on Eocene serpentine; and lastly, the Eocene serpentine with calcite veins known as "verde di Polcevera" of Pietra Lavarezza, just below the Bocchetta Pass, which vies with the similar rock of Levanto in

[1] Near Borzoli occurs the amygdaloidal calcareous diabase called borzolite, and west of Murta the cavernous variety called coschinocite by Issel. Madonna della Guardia is almost entirely built on diabase.

Eastern Liguria.[1] Beyond the Pass, Eocene serpentine and diabasic rocks appear in the Lemmo Valley near Molino di Voltaggio along the Bocchetta road and in the lower part of the Acquastriata ravine, whose upper part lies, however, in calc-schist and pietre verdi. Some further small masses near Voltaggio complete the Eocene fringe.[2]

As regards the anomalous position of the Voltri group east of the Savona massif, there is an obvious correlation between it and the underlying dolomitic limestone, the isolated outcrops of which all round the group can only be remnants of a much more extensive and continuous formation which reached west to the Savona massif and the Maritime Alps. That formation must have been overlain by a similarly extensive one of calc-schists and pietre verdi ; hence, in the intervening gap in the Savona region the two formations must either have been removed by erosion and denudation or they must have been pushed over from the Maritime Alps. The gap in the Savona region between the calc-schists and pietre verdi in the north-eastern part and those of the Bormida Valleys on the western margin is only about 15 kilometres ; it may, therefore, be legitimately assumed that the gap was simply eroded, that both the Triassic formations—dolomitic limestones and calc-schists with pietre verdi—originally extended from the Maritime Alps continuously to the Voltri group, and that the latter, of submarine sedimentary and eruptive origin, was formed in situ rather than by an overthrust from the west. In either case it is, by reason of its Mesozoic age, geologically Alpine in character, and constitutes, together with the Savona crystalline massif, the contact-zone of the Alps and the Apennines.

[1] The serpentine of Pietra Lavarezza with associated ophicalce is overlain by diabase which forms the left bank of the upper Riasse torrent. In the Recreusi glen, where the unconformable contact of the Triassic limestone and the overlying Eocene argillaceous schist is conspicuously exposed, occur, along the junction of the Eocene ophiolithic rocks, large masses of Triassic gypsum which are quarried near Isoverde.

[2] Since this paper first appeared an interesting petrographic study by A. Martelli has come to my notice on "Metamorfismo sul contatto fra serpentine antiche e scisti a Campo Ligure": Boll. Soc. geol. ital., 1913, p. 285. It shows that the serpentinous schists of the Voltri Group are derived not only from peridotitic but also from augititic and hornblendic rocks which have been rendered pseudo-morphous, i.e. altered to serpentinous schists through contact with the infolding calc-schists. This agrees with the definition I have, in various papers of this volume, given of serpentinous schist as *pseudo*-serpentine ; it is, however, produced not only by contact but often by pressure under high temperature.

IX.

The Ophiolithic Groups of the Ligurian Apennines. Eastern Liguria.

General Features.

THE three principal ophiolithic groups of this region are those of Levanto, Monte Bianco, and Monte Penna, about midway aetween Spezia and Genoa, viz. north of Levanto, Sestri Levante, bnd Chiavari, at average altitudes of 300, 800, and 1,600 metres respectively. Like the Eocene ophiolithic group of Sestri Ponente and Isoverde, west of Genoa, they lie in the upper horizon of that formation, that is, in the fossiliferous (fucoids) albarese limestones and the argillaceous schists which rest on the Middle Eocene macigno sandstone as the lowest member of the Ligurian Eocene. The sedimentary and infolded ophiolithic groups, consecutively aligned from the coast to the crest of the Apennines, form a series of anticlines north to south, dipping west, with some transverse folds. The whole region is greatly contorted and brecciated ; it is, moreover, profoundly eroded by torrents charged with calcium carbonate which has accelerated erosion and at the same time re-cemented breccia. Although the three groups are now separated, they are, together with the scattered islands north of the crest of the Apennines towards Piacenza in the Po Valley, only the remnants of an originally continuous formation of no less than 1,500 square kilometres or 600 square miles.

The principal ophiolithic rocks of the three groups are serpentine, euphotide, and diabase, with their varieties. The serpentine is both compact and schistose, and often of porphyritic structure. There is no passage from serpentine to the other two rocks, but there are frequent transitions between the latter ; serpentinous schist or pseudo-serpentine, often in transition to argillaceous schist, is also much in evidence. Associated rocks are the semi-crystalline schists known as *flaniti* and *diaspri*, viz. silico-calcareous, reddish and green schists, harder than limestone, indurated by taking up silica at the expense of lime, and containing radiolaria. Both, and notably the more highly indurated diaspri, form bands on the margin of ophiolithic rocks in proximity to calcareous masses.[1] It is a noteworthy feature that metalliferous deposits are found only in euphotide and diabase, never in serpentine, though often near the contact of the latter ; again, manganese occurs, not in the ophiolithic rocks proper, but in the diaspri masses, though in the vicinity of the former.

[1] Indurated, silico-argillaceous schists are known as *galestri*, yellowish, red, or green in colour ; *ardesia* are tegular, silico-argillaceous-calcareous schists ; and *resinite* is a white or yellowish siliceous, semi-opaline variety.

I. The Levanto Group. (Figs. 1 and 5.)

This extends along the coast from Monterosso to Levanto, Bonassola, and Framura for about 10 kilometres, and inland about 20 kilometres to north of La Baracca on the high-road from Sestri Levante to Spezia. The precipitous, craggy outcrops along the coast are composed chiefly of greenish and dark reddish serpentine and of euphotide alternating with argillaceous schist all more or less decomposed, except the euphotide with felspathic base and smaragdite of Bonassola, which, though it exhibits secondary minerals, is comparatively fresh.[1] The principal outcrops inland are exposed along the road from Levanto to La Baracca (600 m.), where the ophiolithic series may be conveniently studied in the numerous quarries of the beautiful and well-known " green marble of Levanto ", largely used for ornamental purposes. It is essentially compact serpentine, greenish and rusty red, with clear white veins which are fissures filled with calcite. The rock passes to a more crushed and brecciated variety, re-cemented by calcium carbonate as ophicalce. Another variety is the so-called *ranochiaia* or frog-coloured, which in a greenish yellow groundmass exhibits fine, black, arborescent tissues of opacite. The compact serpentine also passes to schistose, fibrous, and steatitic, is often spheroidal, and, when it contains enstatite, diopside, bronzite, and notably diallage, is porphyritic in structure. Along the same road serpentine often alternates with euphotide more or less altered, and with intermediate strips of pseudo-serpentine. The ophiolithic rocks are normally intercalated between argillaceous schists as the lower, and limestones as the upper strata, with occasional intervening claret-coloured diaspri. North of the Sestri and Spezia road occurs the cluster of serpentine and euphotide masses of Tavarone between Castiglione and Maissana, of Velva, Carro, Baracchino, and Matterana (Bracco), in all of which the euphotide is largely gneissiform and, notably north of La Baracca, forms a considerable area. Another interesting mass is that near Pignone, about 10 km. east of Levanto and the same distance north of Spezia, which constitutes, in the Eocene strata, a band of about 8 by 1 km. of serpentine and euphotide, like those of the Levanto group.[2] It runs north-west to south-east, parallel to the latter and to the coast towards the Cretaceous, Liassic, and Rhætian strata of the Porto Venere or western arm of Spezia Bay, and forms the link between the ophiolithic groups of Eastern Liguria and those 15 km. further east of Sarzana, Lunigiana, and Garfagnana in the Magra and upper Serchio Valleys along the northern margin of the Apuan Alps.

[1] A few of the rocks near Levanto were described by Professor Bonney in op. cit., Geol. Mag., 1879, p. 362 et seq.

[2] Specimens of the Pignone group were examined microscopically by Professor A. Cossa of Turin, who also gives analyses of the same in comparison with some of the similar Ligurian and Tuscan rocks (Boll. R. Com. geol., 1881, p. 246 et seq.).

Sketch Map of Ophiolithic Groups, Eastern Liguria

A = Arg. Schist ; E = Euphotide ; D = Diabase ;
S = Serpentine ; C = Limestone ; D = Diaspri.

II. The Monte Bianco Group. (Figs. 1–4 and 6.)

This ophiolithic and remarkably metalliferous area is situated north-west of the Levanto group ; its lower end, touching the Sestri and Spezia road near Bracco (448 m.), lies about 6 kilometres north of the former town. It covers about 10 by 5 kilometres, and is crossed north-east to south-west by the deeply eroded ravines of the Graveglia, Gromolo, and Petronia torrents in its northern, middle, and southern part respectively. It is traversed north to south by three more or less parallel ridges, viz. anticlinal folds dipping west, the highest or eastern of which includes Mte. Porcile (1,249 m.), Zenone (1,072 m.), Alpe (1,096 m.), and Pù (1,007 m.), while the middle one comprises Mte. Bianco (876 m.), Rocco Grande (968 m.), Mte. Treggin (876 m.), and Mte. Loreto (360 m.), and the western descends to 400 and 300 m. altitude.

The ophiolithic rocks are infolded in the usual Eocene sedimentary strata, notably fine-grained, bluish-white, nodulous, and banded limestone, and argillaceous schists, frequently tilted almost vertically. Serpentines predominate more especially in the eastern, diabase and euphotide in the western and central part ; their proportion may be roughly estimated as being 2.5, 2.5, and 1.5 respectively.[1] The northern margin of the group is, between the ophiolithic rocks on one side and the calcareous rocks on the other, fringed by bands of claret-coloured diaspri up to one kilometre in width, which crop out on some of the highest points of the middle and eastern ridges such as Mte. Bianco, Rocca Grande, Mte. Treggin, Porcile, and Alpe. The principal roads leading from the coast up into the hills are those from Sestri to Casarza and Castiglione (271 m.) along the Petronia Valley in the southern, and from Lavagna along the Graveglia Valley to Nascio (390 m.) in the northern part of the area, as also the roads up the Gromolo Valley to the Libiola mine (380 m.) and from Casarza to Bargone in the centre of the area. The first of these more especially crosses in succession the serpentine, diabase, and euphotide masses in a natural section west to east of about 4 kilometres, along the Petronia Valley between Casarza and Castiglione. This section is very similar to a larger, parallel one across the widest and central part of the group from the Gromolo Valley to Rocca dell'Aquila, Rocca Grande, and Monte Zenone, cutting the three anticlinal folds and the synclines between them. These sections and another interesting one along the Libiola road, showing nodulous diabase and euphotide veins in serpentine, are represented in Figs. 2, 3, and 4.[1] Throughout these sections the euphotidic masses more than the other rocks are greatly altered, and often decomposed ; the contact with serpentine is always distinct, while euphotide and diabase constantly merge into each other.

The euphotidic and diabasic masses throughout the area contain considerable nodules of copper pyrites which are worked in a number of mines, some of whose approach-tunnels afford interesting

[1] These sections are deduced from L. Mazzuoli's in "Formazioni ofiolitiche della Riviera di Levante, Liguria" : Boll. R. Com. geol., 1892, p. 2 et seq.

Sketch Map of Ophiolithic Groups, Eastern Liguria.

Fig. 5. Levanto Group. Fig. 6. Monte Bianco Group.
Fig. 7. Monte Penna Group.

exposures. One of these is notably the Libiola mine above the hamlet of that name and in the Gromolo Valley on the western margin of the area at about 350 metres altitude, in a diabasic island of a serpentine mass. The green and reddish diabase here is not only compact but forms numerous aggregations in which nodules of pyrite are embedded and separated from the encasing rock by thin strips of white resinite. In another mine on the left of the Gromolo torrent nodulous euphotide appears encased in serpentine, which is completely altered to steatite. Manganese is found only in the diaspri bands, while serpentine throughout is devoid of metalliferous deposits, as previously stated, though they often appear in close proximity to it.

It was urged at one time as a remarkable phenomenon that in Eastern Liguria serpentine always appears superposed on euphotide and diabase, whereas in other parts of Italy, e.g. in Tuscany, the reverse is the case.[1] The former phenomenon is, however, apparent rather than real, being due not only to the effects of erosion which sometimes expose the outcrops at abnormal levels, but more especially to faults and inverted folds in connexion with the greatly disturbed stratigraphical condition of the whole region. Of this condition a striking example is afforded in the very centre of the area by Monte Treggin (870 m.), a sharply pointed, rugged peak, which is not only surrounded by chaotic masses of breccia and rock-débris, but is itself a confused agglomeration of the ophiolithic and sedimentary rocks of the area, strangely brecciated, crushed, intermixed, and contorted. This phenomenally disturbed condition extends from Mte. Treggin north to the serpentine mass of Mte. Bocco (1,027 m.), and south to the ophiolithic masses near Bargone and Mte. Loreto across the Bargonasco and Petronia Valleys; it constitutes, in fact, an eminently cataclastic zone which runs north to south midway of the area and also from La Baracca along the western margin of the Levanto group down to the coast near Bonassola.

III. The Monte Penna Group. (Figs. 1 and 7.)

This extensive ophiolithic area, the most northern of the three groups, lies north of Chiavari, whence Monte Penna, the highest point of the Ligurian Apennines (1,735 m.), forms a conspicuous object, distant about 25 kilometres. The group comprises a series of mountains disposed, on the crest of the Apennines, in a semicircle facing west and about 15 kilometres in length. In the centre of this semicircle, at 550 metres altitude, or nearly 1,200 metres below the crest, lies the village of Prato, one of a cluster of hamlets called Sopra la Croce, which possesses a mineral spring. About 900 metres above Prato, on Prato Molle, rises the Penna torrent, which, together with its numerous affluents, collects the drainage of the southern watershed of the Monte Penna group and discharges into the Sturla torrent at Borzonasca (160 m.). This village, about 15 kilometres from Chiavari, is the starting-point for the western and central part

[1] See an earlier memoir by L. Mazzuoli and A. Issel, "Studi sulle masse ofiolitiche della Riviera di Levante": ibid., 1881, p. 313 et seq.

of the group, while the eastern part and Mte. Penna itself are also reached from S. Maria del Taro (700 m.). From west to east the group comprises Mte. Ajona, Cantomoro, Nero, Penna, Scaletta, Rocchetta, Pertusio, and Ghiffi, with the western lower spurs of Mte. Agugiaia, Campo Rondio, Mte. Bregaceto, and Mte. delle Lame, while Rocca Borzone forms a spur at the eastern extremity.

The ophiolithic rocks, chiefly composed of peridotite, lherzolite, serpentine, diabase, and their breccia, are, like those of the Levanto and Monte Bianco groups, infolded in Eocene argillaceous schists, limestone, and sandstone, and follow, with the latter, the same general direction north to south, dipping west, although the folds and alternations of both series are often so brecciated as to defy delimination. Between Borzonasca and Prato the sedimentary strata give place in the upper part to brecciated limestone and diabase, whose repeated alternations are followed by a mass of diaspri wedged between diabasic breccia, and then by large masses of spheroidal diabase. From Prato, which lies in normal sedimentary strata, to Mte. Agugiaia (1,088 m.) the outcrops again disclose brecciated alternations with spheroidal and variolitic diabase, then a large mass of reddish bastitic peridotite which forms the cupola of Campo Rondio, and is surrounded by diabase and an outer fringe of argillaceous schist. Diabase is again in evidence on Mte. Bregaceto (1,171 m.) and extends to Mte. delle Lame (1,304 m.), which, though covered with plantation, exhibits that rock on its lower flanks.

From Mte. delle Lame the crest is reached on Mte. Ajona (1,692 m.), on whose comparatively broad and flat surface appears a very hard, dark-red, and rusty-coloured peridotitic rock in superposed layers like flagstones, with reticular ribs and wrinkles evidently due to atmospheric denudation. This rock, which is strongly magnetic and extends considerably north of the crest, obviously passes to serpentine on the southern flank, where serpentinous and limestone breccia appear infolded in argillaceous schist. The crest of Mte. Nero towards south-east of Mte. Ajona exhibits the same peridotitic rock passing to serpentine, and so does the remarkable outcrop of Pria Borgheise, a boss on Prato Molle (1,496 m.), below Mte. Nero, which was first noticed by Mazzuoli, and, thanks to Professor Cossa's microscopic examination, was recognized as the first example of lherzolite in the Ligurian Apennines. East of Mte. Ajona rise Mte. Cantomoro and the peak of Mte. Penna, both composed of diabase, which also applies to Mte. Scaletta south-west of Mte. Penna. These three mountains obviously form a central mass of diabase between the peridotitic and serpentinous masses on the west and those of Mte. Pertusio on the east. Mte. Scaletta and Mte. Pertusio are separated by the argillaceous schist and limestone breccia of Mte. Rocchetta. The semicircular group is completed by Mte. Ghiffi, on whose northern flank appear limestone and breccia, the contact of these rocks and the serpentine of Mte. Pertusio being exposed in the saddle between the two mountains. On the descent from here by

Rocca Borzone the hard diabasic breccia with associated diaspri appear again, being evidently connected with those already noticed above Prato. A notable feature of the Mte. Penna group is the absence of superficial outcrops of euphotide, though that rock probably occurs in places below the surface where the latter is covered with vegetation or detritus, in association with diabase and serpentine as it does in the other ophiolithic areas of Eastern Liguria. North of the Mte. Penna group, about a dozen ophiolithic, chiefly serpentinous islands crop out in the Trebbia, Aveto, and Nure Valleys near Bobbio, S. Stefano, and Ferriere respectively, towards Piacenza in the Po Valley ; they are obviously a continuation of the Ligurian groups.[1] The diabasic masses of Mte. Cantomoro, Penna, and Scaletta extend south-east, towards Varese-Ligure, to Mte. Quatese, Cavallone, Setterano, and Carignone, all at about 1,300 metres altitude, in three more or less parallel zones with intervening strata of argillaceous schist containing abundant lenticular intercalations of diabasic breccia, of which extensive agglomerations also appear on the northern flanks of Mte. Penna. The diabasic zones obviously represent original submarine lava streams flowing in the planes of the plastic sedimentary strata in which the débris became infolded and cemented to breccia.

Conclusion.

The phenomena presented by the ophiolithic and sedimentary groups of Eastern Liguria are substantially the same as those of the Triassic Voltri and the Sestri and Isoverde Eocene groups west of Genoa. Both regions afford striking evidence of intense folding, crushing, contortion, and brecciation which the sedimentary and the ophiolithic rocks of submarine eruptive origin during their contemporaneous uprise and subsequent settling experienced alike. There is no tangible evidence of these groups being transported areas, while everything points to their emergence and location in situ.[2] The effects of repeated earth-movements, including those of a seismic character, are strikingly evidenced by the frequently cataclastic condition of the Ligurian littoral from the coast to the crest of the Apennines and the compression of the region during its uprise and settlement must have been all the greater considering that it lies in the contracted semicircular curve of the Gulf of Genoa.

[1] L. Mazzuoli, "Formazione ofiolitica nella Valle del Penna": Boll. R. Com. geol., 1884, p. 384 et seq. A. Cossa, "Intorno ad alcune roccie della Valle del Penna nell'Apennino ligure": Rendiconti R. Accad. Lincei, Roma, 1886, pp. 502 and 643 et seq. Professor Cossa, of Turin, also first examined microscopically some of the ophiolithic rocks on the north of the Apennines: "Sopra alcune roccie serpentinose dell'Apennino Bobbiese": Boll. R. Com. geol., 1881, p. 58 et seq.; also D. Zaccagna, Relazione, 1902; ibid., 1903, p. 39.

[2] Further east towards Spezia the Mesozoic and Tertiary sedimentary strata exhibit an abnormal superposition which has always been regarded as an extensive inverted fold, but may be the effect of a local overthrust. In the ophiolithic areas of Eastern Liguria, on the other hand, the Eocene sedimentary sequence is normal.

X.

The Carrara, Massa, and Versilia Marble District (Apuan Alps).

I. Introductory.

THE range of the Apuan Alps, commonly called the Carrara Mountains, trends, from its junction with the Apennines east of Spezia, as an independent massif N.N.W. to S.S.E., parallel to the Mediterranean littoral, from which it rises within a distance of barely three miles to a maximum height of 6,000 feet above sea-level. Exclusive of the outer belt of the more recent strata, the Triassic formation, which includes the saccharoidal marble beds, covers about 25 by 13 kilometres, or about 130 square miles, of which the marble zone proper represents 64 square miles or about half. The range is bounded on the north by the Aullela valley in the Lunigiana district[1]; on the east by the Serchio Valley in the Garfagnana district ; and on the south by the Serchio Valley in the Province of Lucca. The marble district, whose western part faces the Mediterranean, comprises the three divisions of Carrara, Massa, and the Versilia in the corresponding parallel valleys of the Carrione, Frigido, and Serravezza Rivers. The Versilia division, which forms part of the Province of Lucca, is composed of the Seravezza, Stazzema, and Arni subdivisions, of which the last-named lies on the eastern watershed of the Apuan range. The Versilia division also includes Pietrasanta, Camaiore, Massarosa, and the well-known watering-place of Viareggio, near the last-named of which are situated extensive subaqueous deposits of a peculiarly coarse-grained, sharp maçigno sand. These deposits, formed as a delta in a lacustrine expanse by the River Serchio, constitute an important and indispensable adjunct of the marble industry as grinding material for the numerous marble saw-mills in the three parallel valleys already referred to.

Up to 1880 parts of the marble district had been investigated chiefly by Savi, Coquand, Cocchi, and De Stefani, whose views were in part concordant, in part conflicting ; but it was only subsequently, in the early 'eighties, that the systematic and comprehensive geological survey of the entire range of the Apuan Alps was carried out by Lotti and Zaccagna, of the Royal Italian Mining and Geological Department, under the direction of Professor Meneghini, of Pisa. This survey was completed in the 'nineties by the publication of the Geological Contour Map of 1 : 25,000 (2·54 inches per mile), together with numerous sections. It was in the period of that survey

[1] Lunigiana was the ancient Roman Luna district, the Carrara marble being then called Marmor Lunensis. The Apuan Alps were inhabited by a warlike tribe, the Apuani, subdued by the Romans 180 B.C.

that the present writer had his professional headquarters in the district for several years, during which he acquired an intimate knowledge of every part of it [1] and had frequent opportunities of discussing and verifying the conclusions of those distinguished geologists.[2] It will, therefore, not be out of place to briefly review the outstanding features of that unique and justly famed district from personal experience and observation.

II. Physiographical Features.

If the range of the Apuan Alps could be reconstructed as it was after its uprise in Miocene times, it would represent a flat ellipsoidal dome whose cupola reached an elevation of over 6,000 feet above sea-level. The initial thrust having been exerted on this part, as indeed on the whole of the Ligurian littoral from the south-west, i.e. from the Mediterranean, it is on the side of that littoral that the Apuan Alps are marked by steep and precipitous declivities up to 45 degrees, while on the eastern side they fall away more gradually to the Serchio valley at an average inclination of 20 degrees. Accordingly, denudation and the formation of deeply cut, narrow valleys by fluviatile and atmospheric agency proceeded much more rapidly on the western side, which therefore exhibits a series of sharply defined peaks denuded, in their upper parts, of vegetation and imparting to the range its imposing, conspicuously rugged and Alpine character. On the eastern side, on the other hand, where the process of denudation was less rapid, the mountains, with one or two exceptions, have preserved their dome- or loaf-shaped summit outlines with steep sides, and also more of their original elevation, for it is here that the whole range reaches its maximum altitudes in Monte Pisanino and the neighbouring Monte Tambura. The direction of pressure is also evidenced by the fact that the strata on the western side are much more highly crystalline and resistant than the more fine-grained and softer eastern strata, which, consequently, have been all along the line greatly folded, bent over towards the east, and at many points totally reversed.[3]

[1] In a prize paper, Proc. Inst. Civ. Eng., vol. ciii, 1891, "The Carrara Marble District Railway," I gave a summary description of the district.

[2] The Memoirs and Notes on the district by Lotti and Zaccagna in the Bollettino del R. Comitato Geologico d'Italia are the following:—

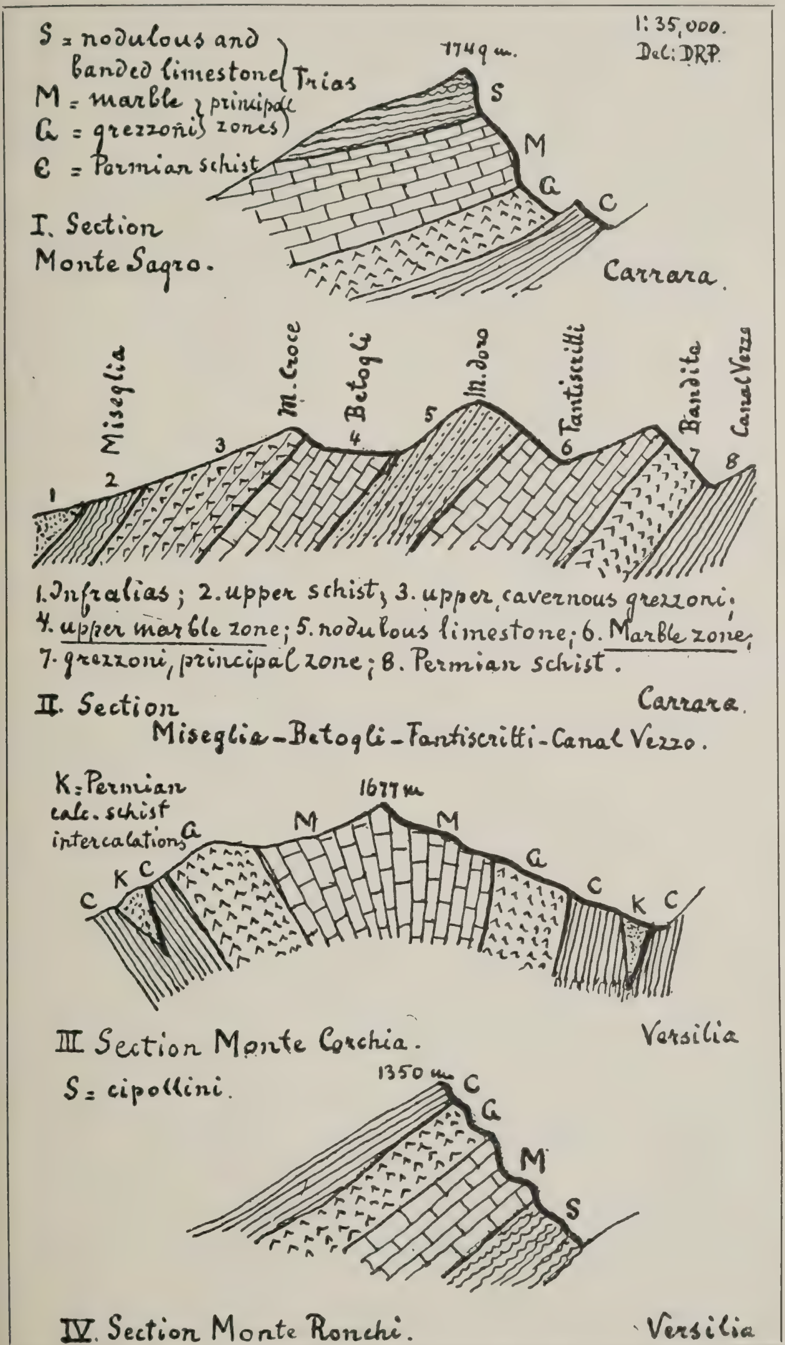
B. Lotti: vol. 1881, pp. 1, 85, 419; and Carta Geol. d'Italia, 1910, p. 372.

D. Zaccagna: vol. 1880; vol. 1881, pp. 1, 476; vol. 1896, p. 214.

B. Lotti is the late Director of the Royal Geological Department, Rome. D. Zaccagna is late Chief Engineer of the same Department and late Director of the Mining Institute of Carrara: he is himself a Carrarese who had, in the words of Dante, "i bianchi marmi per sua dimora."

[3] The fact that in the Apuan Alps the direction of thrust-pressure was S.W. to N.E. in itself suffices to disprove the theory advanced by Steinmann (op. cit.) and others that the Mesozoic beds of that massif and also those of the Tuscan Subapennines generally are not autochthonous but allochthonous areas transported from the Dinarides, i.e. E. to W. Local displacements may and do occur in all autochthonous massifs as the effect of earth movements,

Sections of Apuan Alps. Figs. I–IV.



The range is thus composed of two series of mountains, i.e. of the *pizzi* or peaks of the western, and of the *panie* or loaf-shaped eastern series, the former being about 24 kilometres, the latter about 12 kilometres in length, and the two not running exactly parallel, but converging towards each other. The natural alignment of the range may therefore be described roughly as that of a two-pronged fork as shown in the plan (Fig. V), the intervening space between the two prongs being occupied by the Arni Valley, about 7 kilometres in greatest width at its upper end. The ends of the two prongs are marked by Pizzo d'Uccello and Monte Sagro (Carrara) on the west and by Monte Pisanino on the east; the junction of the two prongs coincides with Monte Altissimo in the Seravezza division, and the southern end of the fork extends towards Pania della Croce and Monte Forato in the Stazzema division. The altitudes of the principal Western Pizzi and the Eastern Panie, which are marked in the plan, are as follows :—

Western Series, 24 km.		m.	*Eastern Series, 12 km.*	m.	
Carrara	Pizzo d'Uccello	1782	Monte Pisanino	1946	Carrara and Massa.
	Monte Sagro	1749	,, Cavallo	1889	
Massa	Cresta Garnerone	1791	,, Tambura	1890	
	Monte Grondilice	1646	,, Sella	1723	
Seravezza	,, Altissimo	1549	,, Fiocca	1711	Arni.
Stazzema	,, Corchia	1677	,, Sumbra	1765	
	Pania della Croce	1859 [1]	,, Freddone	1487	
	Monte Forato	1230	,, Ronchi	1350	

The intervening Val d'Arni lies at an altitude of about 1,000 metres at its upper and of 900 metres at its lower end between Altissimo and Sumbra, where the Arni and Freddone torrents join and under the name of Turrite Secca are deflected to the east as tributary of the River Serchio.

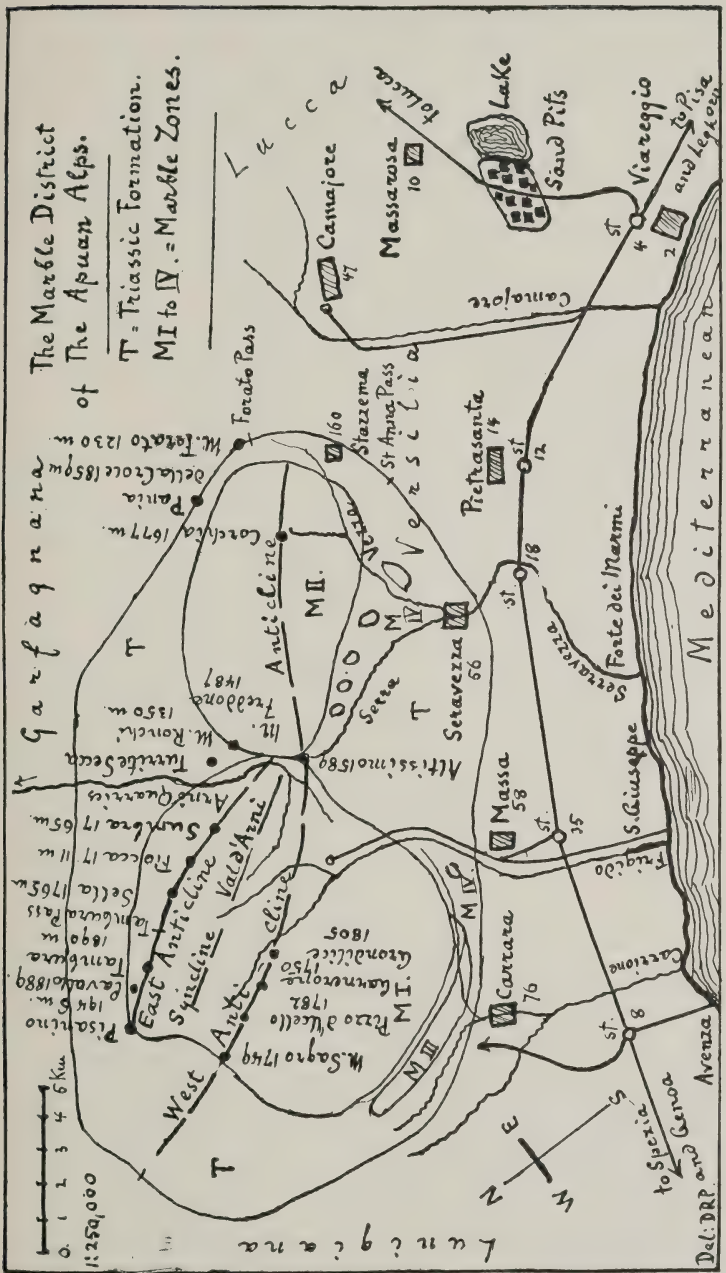
III. The Geological Structure.

The flat, fork-like curves formed by the crest lines of the two series also mark the direction of the two great anticlinal folds of the range, the intervening Val d'Arni being the corresponding syncline, which is eroded down to the substratum of the central schists. The two principal folds are not, however, simply uniform anticlines, but are

compression, or shearing within their own areas, and such displacements take place in different directions. T. Taramelli has recently pointed out that both in the Eastern Italian Alps and in the Northern Apennines some of these local *coltri* or cover-sheets were thrust N. to S., others S. to N., whereas the direction from the Dinarides should be W. to E. "Se l'Appennino settentrionale rappresenti in realtà un carreggiamento": Rend. R. Ist. lomb., 1913, p. 128. "Se le Dinaridi costituiscono veramente una massa carreggiata": ibid., 1913, p. 1009.

[1] This very conspicuous mountain, one of the highest of the series, is really a *pizzo*, its summit being a ridge not more than 10 yards long and barely 2 feet wide. Monte Forato is, as its name implies, remarkable for the great natural arched opening just below its summit.

Fig. V.



The Marble District of the Apuan Alps.

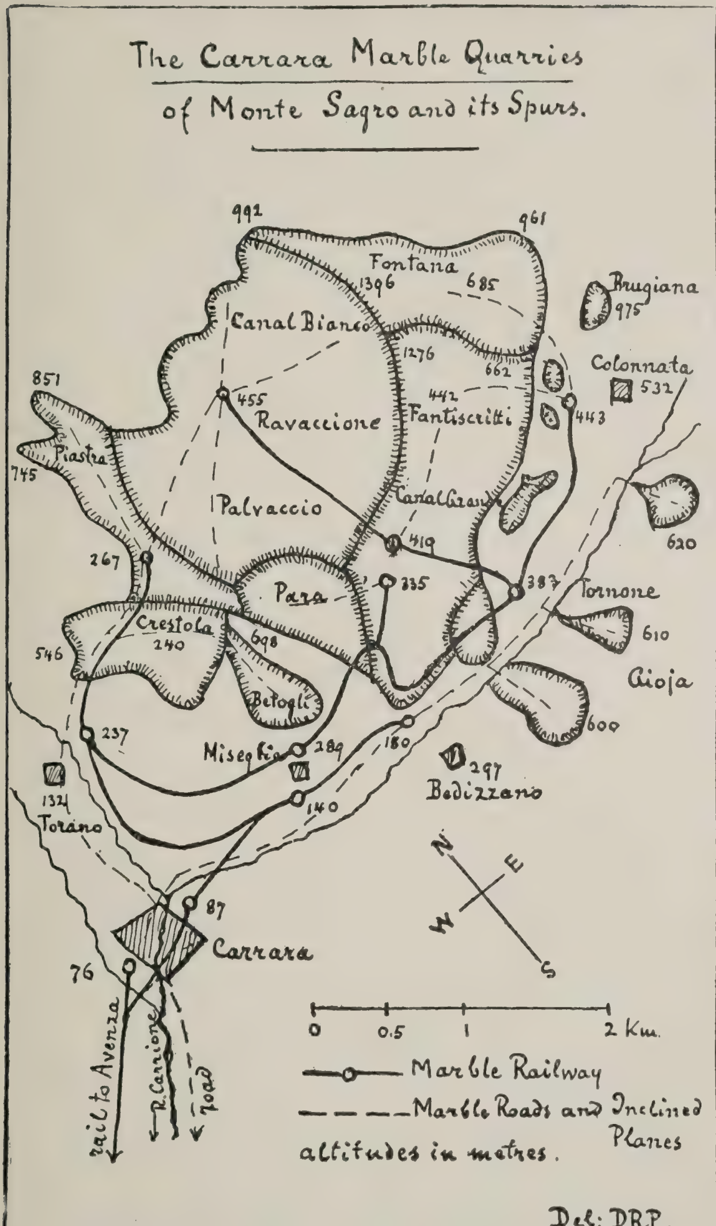
composed of a succession of anticlinal and synclinal flexures which, beginning at the Vinca Pass north of Monte Sagro at the western, and at Monte Pisanino at the eastern end, converge and merge into each other near Monte Altissimo and thence extend to the Stazzema end of the range. The extraordinary multiplicity of these flexures renders their co-ordination extremely difficult, the more so as in many of them, notably in the eastern series, the stratigraphical sequence is reversed, while, more especially at their junction near Monte Altissimo, and also near Renara in the Massa Division, the strata exhibit extraordinary contortions which only long and patient study and sections of minute detail can unravel. The sections given in Figs. I to IV represent some typical examples, Fig. I showing the normal anticline of Monte Sargo, Fig. II a lower part of the same anticline, with the complete stratigraphical sequence from Miseglia to the Betogli and the Fantiscritti quarries above, viz. north-east of Carrara ; Fig. III the normal syncline of Monte Corchia in the Stazzema, and Fig. IV the totally reversed stratigraphical sequence of the contorted flexure of Monte Ronchi in the Arni division, in the junction zone of the two great folds.

All the principal mountains exhibit flexures, more or less accentuated, not only along the precipitous ridges of the crest lines and on the denuded mountain sides, but in the marble quarries, as well as in the cuttings and tunnels of the Carrara Marble railway, all of which thus offer a multiplicity of revealing sections. In some isolated cases, where the visible part of a flexure is too acutely bent, there is a rupture of the lowest synclinal or of the uppermost anticlinal stratum ; but however twisted or reversed the flexures may be, there is throughout the range a total absence of faulting in the sense of fracture or dislocation of the strata. The very fact of the constant succession of normal and abnormal flexures admits of co-ordinating them as components of the two great folds which constitute one of the characteristic features of the range.

IV. The Stratigraphical Sequence.

Proceeding from the Mediterranean littoral upwards into the valleys of the three main divisions, the lower hills, which form the outer fringe of the range about 4 kilometres from the sea, are found to be composed of much folded Eocene alberese limestone and macigno sandstone, succeeded by Cretaceous and then by the Liassic and Rhætian schist and limestone strata. The town of Carrara is built on old alluvial conglomerate resting on those strata. The Lias and Rhætian thence extend as far as Miseglia, about 1 kilometre north of Carrara, at which point begins the sequence of the Triassic and older rocks. From here, at altitude 240 metres—and about the same level in the other divisions—the succession, omitting the minor alternations, may be summarized as follows :—

The Carrara Marble Quarries, Monte Sagro. Fig. VI.



			Depth in metres.
MESOZOIC.			
I. Upper Trias.	1. *Upper Schist, Marble, and Limestone Zone.*		
	Rhætian	(*a*) Upper Schist, sericitic and chloritic, with pseudomacigno sandstone . (*b*) Cipollini and Upper, cavernous Grezzoni, semi-crystalline and dolomitic . .	300
		(*c*) Upper Marble, white, statuary, bardiglio, veined, and breccia	300
		(*d*) Banded and Nodulous Limestone, grey and yellowish	200
	2. *Principal Marble Zone*, white, statuary, bardiglio, veined, and breccia . . .		1,000
II. Middle Trias.[1]	*Principal Grezzoni Zone*, dolomitic, semi-crystalline, dark-grey, brown, and whitish limestone, in part black carbonaceous. .		500
PALÆOZOIC. III. Lower Permian.	*Central Schist Zone*, dark-grey, micaceous and gneissose, with calcareous, talcose schist intercalations		1,000
			3,300

It is thus seen that the upper and the principal saccharoidal marble horizons together represent a visible depth of no less than 1,300 metres, over three-quarters of a mile. As shown in Figs. I to IV, the normal sequence of strata is uniformly the same throughout the three main divisions of the district, the marble of the principal zone resting normally always on the principal grezzoni beds, and underlying the banded and nodulous limestone of the upper series, except in abnormal or reverse flexures. The strata of the upper series frequently alternate with each other, as shown in Fig. II; hence the marble of that series is always associated with one or more strata of that zone.

V. THE CENTRAL AND THE UPPER SCHISTS.

The central schists constitute the lower formation and the nucleus of the range, and round and above them appear concentrically the successive Triassic series including the Rhætian, overlain by Liassic limestone. These central schists were formerly regarded variously as of Archæan, Silurian, or Carboniferous age; but the discovery in 1880 by Lotti and Zaccagna of abundant *Orthoceras* and *Actinocrinus* fossils in the frequent calcareous schist intercalations, notably near Fonte Mosceta in the depression between Monte Corchia and Pania della Croce in the Versilia (Stazzema) division (*vide K* in Fig. III), enabled Professor Meneghini of Pisa to assign the central schist formation definitely to the Palæozoic.[2] Subsequently, in 1883 and

[1] The Lower Trias is absent in the Apuan Alps, the Upper Permian or verrucano is sparsely represented by a coarse conglomerate underlying the Middle Trias grezzoni at a few isolated points of the range, e.g. near Vinca, Pizzo d'Uccello, and in the Arni region.

[2] "Nuovi Fossili delle Alpi Apuane": Proc. Verb. Soc. Tosc. Scienze Naturali, 14th November, 1880.

1885, Zaccagna, who at that time surveyed both the Grajan and the Western Maritime Alps on the Italian side,[1] showed conclusively that not in the former (nor in the St. Gothard schists), but in the latter is found the analogy with, and the equivalent of, the Apuan central schists, the uniform parallelism of the schists and the overlying grezzoni being in both cases precisely the same. Moreover, the fossils found in the Maritime Alps, notably in the Tanaro Valley, were confirmed by Professor Portis [2] of Pisa as indubitably Upper Palæozoic, and hence it is due to Zaccagna that the long debated age of the Apuan central schists was finally determined as Lower Permian.[3]

Between the Permian and the Upper Triassic (Rhætian) schists there is a very essential difference. Apart from their totally different stratigraphical position, the Permian schists are distinguished by their dark and predominantly gneissose, the Upper Triassic schists by their paler, essentially micaceous and lustrous, sericitic texture. On the eastern side of the range, the upper schists often pass into so-called pseudomacigno sandstone ; it is only on the western side that they are more crystalline, sericitic, and chloritic, and, owing to minute quartz nodules, sometimes simulate a gneiss-like appearance. In the extremely rare cases where the lower and upper schists appear in juxtaposition, e.g. for a short instance near Canevara in the Frigido Valley (Massa), owing, not to any faulting, but to the lenticular thinning out of the normally intermediate strata, they graduate into each other. The Permian schists, moreover, nowhere —except in a similar case of lenticular thinning out in the Arni region—are seen in direct contact with the principal marble zone, whereas the Upper Triassic schists are frequently associated with the marble of the upper and also of the principal zone. This intimate association of all the members of the Triassic series, their constant alternation, thinning out—sometimes completely—and compensating each other, and the consequent absence of faulting, constitute indeed the great characteristic feature of the lenticular structure of that Apuan formation.

The maximum outcrop of the Permian schists occurs in the middle part of the Frigido Valley (Massa), whence they extend south-east to the Stazzema division, north-west to Monte Sagro and beyond,

[1] "Alpi Graje": Boll. R. Com. Geol., 1892, p. 322. "Alpi Occidentali (Marittime)": ibid., 1887, p. 416.

[2] "Piante fossili Valle Tanaro, Alpi Marittime": ibid., 1887, p. 417. The fossils of the Middle Trias grezzoni were determined by De Stefani, P.V.S.T. Sc. Nat., vol. 1880 ; those of the Upper Trias series by Meneghini, "Fossili Triassici Alpi Apuane": ibid., vol. v, p. 693 ; and by Canavari, ibid., vol. v, p. 184. Thus, the palæontological evidence of the Apuan Alps is practically complete. The best palæontological and petrological collection of the range, apart from the local one of Carrara, is that of the University of Pisa.

[3] The Permian range of the Maritime Alps forms the divide between Southern Piedmont and the Italian Riviera, known as the Montgioie Mountains, where the Tanaro, an affluent of the Po, has its source. That range is dealt with in paper No. II of this volume.

and east to Monte Tambura and the Arni region. The Upper Triassic schists, on the other hand, together with cipollini and nodulous limestone, constitute an outer belt, forming, among others, the summits of Sagro, Pisanino, Tambura, Fiocca, and Sumbra, while the rugged crests of Pizzo d'Uccello, Garnerone, Grondilice, and Altissimo are—in the last-named case in a reverse flexure—composed of upper cavernous grezzoni. In the anticlinal folds of Monte Maggiore—a marble spur of Monte Sagro—and of Monte Sella, as well as in the syncline of Monte Corchia, the principal marble horizon reaches to the very summits. Pania della Croce, on the other hand, is, in its upper strata, composed of Liassic bluish-grey limestone.

VI. The Marble Beds.

The lenticular marmiferous masses of the Apuan Alps are composed of the four principal groups shown in the sketch-plan (Plate I). The first and largest of these embraces the bulk of the Carrara and Massa, as also the Altissimo, Arni, Sumbra, and Tambura beds. The second group adjoins the first near Monte Altissimo, in the Seravezza division, and thence extends to Monte Corchia and to the end of the Stazzema division. These two groups belong entirely to the principal marble horizon directly overlying the Middle Trias grezzoni. The third and fourth groups, on the other hand, belong to the upper marble horizon, the third group forming the lenticular mass of Crestola and Betogli in the Carrara division adjoining the principal zone, while the fourth group comprises the smaller, isolated lenticular beds of Monte Rotondo, Trambiserra, Capella, and Costa in the Serra and Vezza Valleys of the Seravezza division, as also the outlying Brugiana and Campaccio beds in the Carrara and Massa divisions. The Crestola and Betogli beds of Carrara are separated from the principal marble zone by nodulous and banded limestone; the isolated lenticular masses of the fourth group are all intercalated between the schists, cipollini, and cavernous grezzoni of the upper series.

The varieties and gradations of marble which compose the four groups are substantially the same in all the three divisions. The great bulk of marble is in all cases the ordinary white and highly crystalline, from bianco chiaro (clear white) to the more common yellowish and bluish, representing about 75 per cent of the total, while the statuary proper represents about 10 per cent, and the rest of 15 per cent is made up of the dark and pale blue bardiglio, the blue and violet-veined, and the variegated breccia varieties.[1]

[1] The total annual output of the practically inexhaustible quarries (over 600) of the whole district now reaches 250,000 tons of marble in blocks and for slabs, tiles, ornamental and sculptural purposes, of which Carrara represents about 66, Massa 14, and Versilia 20 per cent. The 150 saw-mills in the three valleys consume about 130,000 tons of Viareggio sand per annum, almost as much as the total output of sawn marble. The wastage of marble in sawing and in the other operations amounts to about 10 per cent of the total. The wastage in quarrying is considerably larger, as is shown by the enormous

By far the largest proportion of marble in the Carrara division—the principal quarries of which are shown in the plan, Fig. VI—is the common white, the bianco chiaro, and the semi-statuary, the latter being used for colossal statues and columns exposed to the action of the atmosphere.

The finest statuary marble—the *statuario* proper—distinguished alike by its intense cream-colour, its transparency, its homogeneous but not too crystalline grain, its bell-like sound under the hammer, and the ease of being worked with the chisel, occurs only in smaller masses, yielding comparatively small blocks for the finest sculptural purposes. In the Massa division, statuary marble only occurs in one locality, at Bottecini, near Forno, in the Frigido Valley, but the lenticular mass is depreciated by chloritic veins. The ordinary white marble of that division, in the Rosceto and Renara Valleys, is less pellucid than that of Carrara, but more fine-grained, and distinguished by its peculiar pearly lustre, albeit with a tendency to become too dolomitic in contact with the underlying grezzoni. It also forms occasional small cavities containing bright quartz crystals known as *stelle*, or stars. To the same category belong the marble beds of the Arni, Sumbra, and Tambura zones, while the great mass of the Monte Altissimo, Giardino, and Falcovaja zone in the Seravezza division is in all respects fully equal to the best ordinary, bianco chiaro, and finest statuary marble of Carrara. Similar to this is the Monte Corchia marble (Fig. III) of the Stazzema division, in which latter also occur considerable masses of fine breccia. The isolated beds of the Seravezza division are all composed of a common, very resistant, bluish-white marble, with occasional dark veins, together with fine blue and veined bardiglio, which equals that of the Para bed of Carrara. Near Colonnata, Carrara, there also occurs a peculiarly black saccharoidal marble associated with the lower grezzoni, the dark colour being probably due to organic impregnations. The *pietra bianca* of Stazzema—as distinguished from marble proper—is a semi-crystalline cipollini variety and, like grezzoni (from *grezzo*, coarse, with rhomboidal fracture), a so-called " bastard " marble.

Very characteristic is the frequent graduation of ordinary white and bianco chiaro marble into statuary, and vice versa, in the

quantities of broken-up marble (*ravaneti*) which encumber the glens and river-beds.

The term " Sicilian marble ", which is sometimes but erroneously applied to Carrara marble, is not used in the district, much less is it a geological term. It is an obvious and purely commercial misnomer, dating from the time of Napoleon I's embargo on exports to England, when Carrara marble was shipped from Leghorn first to Sicily and thence to England under the above *alias*.

The marble beds of Carrara worked by the Romans are those of Ravaccione, Canal Grande, and Fantiscritti, chiefly for colossal statues, columns, and other monoliths. The Altissimo quarries and a road of access were opened in 1518 by Michelangelo, whose modest little cottage is still to be seen at Seravezza with the incisive inscription put by himself: " In questa casa abitò Michelangelo Bounarotti per domar le asprezze di questo paese."

contact and alternation zones of the underlying grezzoni, where rows and patches of so-called *madrimacchie*, or mothermarks, faintly indicate the former lines of stratification obliterated by the action of metamorphism. These brown or ochre marks are obviously impurities infiltrated from the adjoining grezzoni and precipitated by the saccharoidal marble during crystallization, a process which imparted to the statuary marble its high degree of purity.[1] The contact of the white marble with the underlying subcrystalline grezzoni is often marked by thin, brecciated, and schistose (micaceous) layers with various accessory minerals. In contact with the overlying nodulous limestone, cavernous grezzoni, or with cipollini, the passage is effected by alternating bands, and the same applies to the contact with bardiglio, which latter alternates with white marble until one or the other predominates. Again, in contact with the upper schists, the white marble shows thin streaks of talcose, chloritic, lustrous mica, and the same is the case in the veined and breccia varieties. The violet-veined marble called *paonazzo* owes its delicate violet tint to streaks of minute oligist and pyrite crystals. The breccia of the metalliferous Stazzema division also exhibits metallic and micaceous streaks, while the bright-red, wavy marks are due to infiltrations of iron.[2] Within the last few years, masses of vividly coloured and brecciated marble have also been found in the Rhætian and Liassic limestone beds of the Camaiore basin east of Stazzema.[3]

Statuary marble, graduating from grezzoni below to ordinary white and bianco chiaro above, occurs in inconsiderable depth more or less in all the principal Carrara quarries from Piastra to Ravaccione, Canal Grande, Fantiscritti, Fontana, Colonnata, and Gioja, while the most abundant and celebrated, because purest and most durable *statuario* occurs in the Polvaccio, Crestola, and Betogli quarries of the Carrara, and in the Altissimo and Falcovaja quarries of the Seravezza divisions.

The most striking and conclusive phenomenon in relation to the statuary marble is that, apart from the lower zones of the marble beds, it occurs also in the very heart of ordinary white marble. This is conspicuously the case in the Polvaccio quarry already mentioned where the finest *statuario* forms the nucleus of the saccharoidal mass, and gradually passes into ordinary white marble, the latter being here, as the equivalent of madrimacchie, marked by a zone of dusty dark streaks, and hence termed *macchiato*. The intimate association of statuary and ordinary marble is thus conclusively demonstrated.

[1] *Vide* the Petrographic Note at the end of this paper.

[2] The highly coloured breccia of the Stazzema division has always been considered the best of the Apuan Alps, and was extensively quarried already in the sixteenth century for the churches and palaces of Florence under the Medici régime.

[3] D. Zaccagna, Rassegna mineraria, Torino, 1913, p. 241.

VII. Conclusion.

Throughout the marble beds in their different varieties and gradations there is very little, if any, faulting, nor any evidence of crushing, which, if it did exist, would of course render the marble industrially worthless. So far from the marble beds being in any way associated or contemporaneous with the central Permian schists, they form one and all an integral part of the Triassic series which, from the lower grezzoni to the upper Rhætian schists, in stages of metamorphism varying according to the effect of pressure and high temperature upon the original rock material, constitute the Lower Mesozoic formation of the Apuan Alps.[1] The stratigraphical sequence of this massif, perfectly regular and built up in situ, has its counterpart in that of the Pisan Hills, and as regards the marble beds, even more strikingly in the Siena Hills, both of which will be considered in the next paper (No. XI, Part II) as forming part of the Permian and Triassic Belt of the Tuscan Subapennines.

APPENDIX I.

Petrographic Note.

1. *Marble.*—The numerous slides of white marble of the Carrara, Massa, and Versilia divisions, which I have examined at various times, have always given substantially the same result, i.e. an almost constant regularity and uniformity of structure and composition, varied only by the degree of fineness, of grain, purity, and colour. The homocrystalline matrix of calcite, slightly veiled here and there by streaks of dolomitic or calcareous film, always contains some dolomite, quartz, and micro-crystals and microliths of various accessory minerals. In the more dolomitic varieties, i.e. those of Massa and of Arni (Seravezza division), the dolomite crystals exhibit a strikingly pearly lustre. The accessory micro-minerals appear either disseminated in the matrix or form lines and streaks in the same. They increase, as a rule, in number from the white statuary to the more common white and the coloured varieties of marble,

[1] An additional feature of interest in the Apuan Alps is the evidence of former glaciation. Stoppani, as early as 1872, was the first to point out a detritus cone of striated material at the lower end of the Arni Valley (R. Inst. Lomb. Sci. Nat., vol. v, p. 733; also Atti Soc. It. Sci. Nat., Aprile, 1875). Similar deposits and erratic blocks occur at high levels in the Carrara valleys and on the slopes of Pisanino, Tambura, Sumbra, Pizzo d'Uccello, Altissimo, Pania della Croce, and Corchia; and Zaccagna met with conspicuous *roches moutonnées* on a calcareous schist ledge in the Gramolazzo (Upper Serchio) Valley, about 50 metres in length. A more detailed notice of these glacial phenomena would exceed the scope and limit of the present paper. The partial Post-Pliocene glaciation of the Apuan Alps has also been confirmed by C. De Stefani, Le Pieghe delle Alpi Apuane, Firenze, 1889, p. 51; T. Taramelli, "L'Epoca glaciale in Italia," Atti soc. scienze, Roma, 1910.

and are primary minerals as distinguished from those associated with the secondary quartz geodes which were formed in cavities and fissures after the metamorphism of the limestone to saccharoidal marble. The accessory minerals which appear in slides as micro-crystals and microliths comprise albite, epidote, sericite, chlorite, tourmaline, rutile, oligist, limonite, pyrite, magnetite, and traces of sulphur probably due to metamorphosed organic particles.[1]

2. *Grezzoni.*—This subcrystalline limestone, immediately underlying the saccharoidal marble beds, shows in slides incomplete crystallization of the calcitic and dolomitic matrix, with a calcitic paste, and a more oolitic, incipiently spheroidal structure than marble proper. The chlorite as accessory mineral figures here as the chloritoid, monoclinic variety called ottrelite, together with quartz and some of the other micro-minerals already named.[2] The dark, in places carbonaceous grezzoni contain dark-grey and black particles of organic origin.

A peculiar combination of fragments of marble and grezzoni occurs frequently at the contact of the two in thin lines and layers cemented by a micaceous and calcareous paste, and exhibiting micro-crystals of lamellar chlorite (ottrelite). These lines and layers are not unlike the *madrimacchie* streaks which generally occur at the base of statuary marble, and their origin by precipitation of impurities along the contact fissures of marble and grezzoni is probably the same.

3. *Breccia.*—This term relates, in its local meaning, to a brecciated rock in which the fragments are less vividly coloured than the bright brick-red cement, whereas in the so-called *mischio* or *brecciato* (i.e. mixed breccia) the rock fragments are so intensely coloured that they blend with the red cement. Slides show that this red colour is entirely due to a profuse dissemination of iron oxide; the paste also reveals disseminated spathic, often twinned ottrelite and lines and streaks of oligist, pyrite, mica, etc. The angular fragments of marble and grezzoni exhibit in slides the characteristics already stated. Sometimes the breccia becomes so chloritic as to constitute ottrephyre, i.e. a flesh-coloured, whitish and yellow rock which in slides reveals a granulitic groundmass of quartz, white mica, and

[1] Most of these accessory minerals also occur as secondary minute crystals in the quartz geodes or *stelle*, described by Professor G. D'Achiardi in his mainly crystallographical memoir, "I Minerali dei Marmi di Carrara," Atti soc. tosc. Pisa, 1905 and 1906. In these geodes he also found malachite, azzurrite, scapolite, an amphibolic or pyroxenic mineral, etc. The memoir is largely founded on specimens of D. Zaccagna's rich collection of Apuan rocks, now in the University of Pisa. This collection will also form the basis of S. Franchi's lithological studies of Apuan rocks to be published by the Italian Geological Survey.

[2] The determination of the chloritic mineral in the Apuan rocks as ottrelite is in the first instance due to the late Professor A. D'Achiardi, of Pisa ("Roccie ottrelitiche delle Alpi Apuane," Pisa, 1887), which mineral is largely and characteristically diffused in the brecciform gneissose rocks of Ottrèz, Belgium.

monoclinic felspar with profusely disseminated ottrelite, and also other accessory micro-crystals, e.g. tourmaline, rutile, etc.

4. *Upper Triassic* (*Rhætian*) *Schist.*—Slides of this schist of gneissic appearance, which overlies the marble beds, as the youngest member of the Apuan Triassic formation, exhibit silvery (damouritic) sericite with quartz nodules, no felspar, but numerous sheaves of spathic ottrelite, yellow-green, bluish-green, and olive-green, according to the axis exposed, and often twinned. Macroscopically this variety of chlorite appears as black specks. The micro-crystals of accessory minerals are much the same as those in the other rocks. The schist of the western, more highly crystalline side of the massif is richer in ottrelite-chlorite than that of the eastern side, where the schist becomes more granular and arenaceous. The schist shows evidence of shearing, but not of crushing. The gneiss-like appearance is due to the nodules of quartz. When these quartz nodules become dominant and the sericite is subordinate, the rock loses its schistose character and becomes gneissose and brecciform, composed chiefly of quartz, mica, and ottrelite.

5. *Permian Schist.*—This gneissose or central schist as the substratum of the massif exhibits in slides a fine to medium grained matrix of abundant quartz and sometimes pale and lustrous, sometimes dark brownish mica ; felspar is absent. The rock shows in all cases not only foliation and shearing, but marked evidence of crushing. The greater the proportion of grains and nodules of quartz, the more the rock approaches to gneiss ; inversely, when mica is more dominant, the rock is a mica-quartz schist. The accessory minerals as micro-crystals in the central schist are much the same as in the Triassic schist, but tourmaline is much more abundant, together with chlorite, rutile, and oligist. The Apuan gneissose schists are, both macroscopically and microscopically, the exact equivalents of the Permo-Carboniferous schists of Elba, Savona, and the Piedmontese Alps.

6. The most outstanding feature revealed by microscopic examination of marble of the three divisions is the total absence of any evidence of crushing, which latter, on the other hand, eminently characterizes the Permian gneissose schists. This essential difference alone suffices to prove that the two formations are quite distinct in origin, character, and age.[1]

[1] The total absence of crushing in the marble and limestone beds conclusively disposes of Professor Bonney's hypothesis (Geol. Mag., 1915, p. 294) that the best Carrara marbles (as if these could be singled out from the others) and the crushed gneissose schists (the Permian substratum of the massif) constitute together one and the same Archæan formation.

The rocks of the ophiolithic groups which skirt the northern margin base of the Apuan Alps are referred to in Paper No. XII, Part II.

D. R. P.

ITALIAN MOUNTAIN GEOLOGY.

PART II.

THE SUBAPENNINES, THE TUSCAN VOLCANIC GROUPS, AND ELBA.

XI.

The Permian and Triassic Belt of the Tuscan Subapennines.

THE sedimentary formations of Tuscany may be broadly divided into two principal, more or less parallel zones running N.W. to S.E. ; one, the Apennines or eastern zone, composed in the main of Eocene strata, and the other the Subapennines or western zone, which comprises the much more interesting, because more varied, so-called metalliferous range between the Apennines and the Tyrrhenean Sea. The latter zone, whose outer belt consists largely of Permian and Triassic strata, is older than, and independent of the former, and, beginning at the eastern hills of Spezia Bay, embraces the Apuan Alps or Carrara Mountains, and, in Tuscany proper, the Hills of Pisa, Siena, and Grosseto down to Monte Argentario on the Tyrrhenean coast. The Lower Permian and the Triassic formations of the Apuan Alps, of which latter several outcrops also appear at Cape Corvo, the eastern promontory of Spezia Bay, were already described in a previous paper ; [1] the object of the present one is to briefly consider the outstanding features of the Permian and Triassic groups of Tuscany proper.

I. The Pisa Hills. (Figs. 1, p. 107 ; 2, p. 111.)

The Permian and Trias.—The group known as Monte Pisano lies between Lucca and Pisa, and is bordered on the north and west by the Serchio Valley, on the east by the low-lying Bientina depression, and on the south by the lower Arno Valley, thus forming an isolated massif which, with the exception of the Serchio defile on the west and a small Eocene outcrop in the hill of S. Ginesio (S. Leonardo) on the north-east, is surrounded by Quaternary deposits. The Serchio defile separates it from the range of hills called " Oltre Serchio ", which lies between Lucca and the coast of Viareggio and forms the geological link between the south-eastern spurs of the Apuan Alps and Monte Pisano, the three littoral ranges being zonally aligned N.W. to S.E. The Monte Pisano group covers an oval-shaped area of 30 and 10 km. in length and width respectively ; its highest points are Mte. Serra (918 m.) in the east and Mte. Faeta (829 m.) in the north ; other prominent points, such as Mte. Maggiore and Mte. Penna in the west, Mte. Verruca, Punta Dolorosa, and Mte. Cascetto in the south, and Mte. delle Conserve in the north, vary from 500 to 800 m. altitude.

[1] " The Carrara, Massa, and Versilia Marble District " : *vide* Part I of the present volume. As shown in this and other papers, the gneissose schists, as substratum of the Apuan Alps, belong to the Lower Permian or Permo-Carboniferous, corresponding to the same horizon in Western Liguria and the Maritime Alps, where it is overlain by the Upper Permian or Verrucano.

The whole southern, eastern, and northern part, viz. about 200 sq. km., or two-thirds of the group, is occupied almost exclusively by the Upper Permian, so-called Verrucano formation, whose fairly uniform composition, with few exceptions, is in upward succession as follows :—

4. Green and violet tegular argillaceous schists.

3. Quartzose conglomerate (anagenite), arenaceous quartzites, and arg.-micaceous schists.

2. Alternations of quartzose schists with quartzose sandstone and green micaceous quartzites.

1. Dark violet tegular schists and violet quartzose sandstone.

The varicoloured phylladic schists often exhibit sericitic lustre and contain quartz nodules and traces of organic remains ; the upper series generally forms narrow bands between the conglomerate and the occasionally overlying Rhætian. The sequence as stated above appears notably and characteristically in the outcrops of Mte. Verruca, whose summit (536 m.), crowned by a ruined castle and conspicuously seen from the Arno Valley above Pisa, is composed of the typical Permian clastic rock or quartzose conglomerate whence the local designation of Verrucano is derived.[1] Other easily accessible exposures in the southern part of the area are those in the glen above the Certosa of Calci towards Mte. Cascetto and Punta Dolorosa (680 m.), whose upper part is composed of the same conglomerate and quartzose sandstone as Mte. Verruca. A similar sequence appears in the northern part of the group near Vorno and between Mte. delle Conserve and Mte. Faeta, as also on the eastern flanks towards Bientina in the Capo di Via glen and near Cucigliana, where the conglomerate with pink quartz is traversed by quartz veins with oligist crystals and, as Busatti has shown,[2] contains abundant fragments of black tourmanilite.

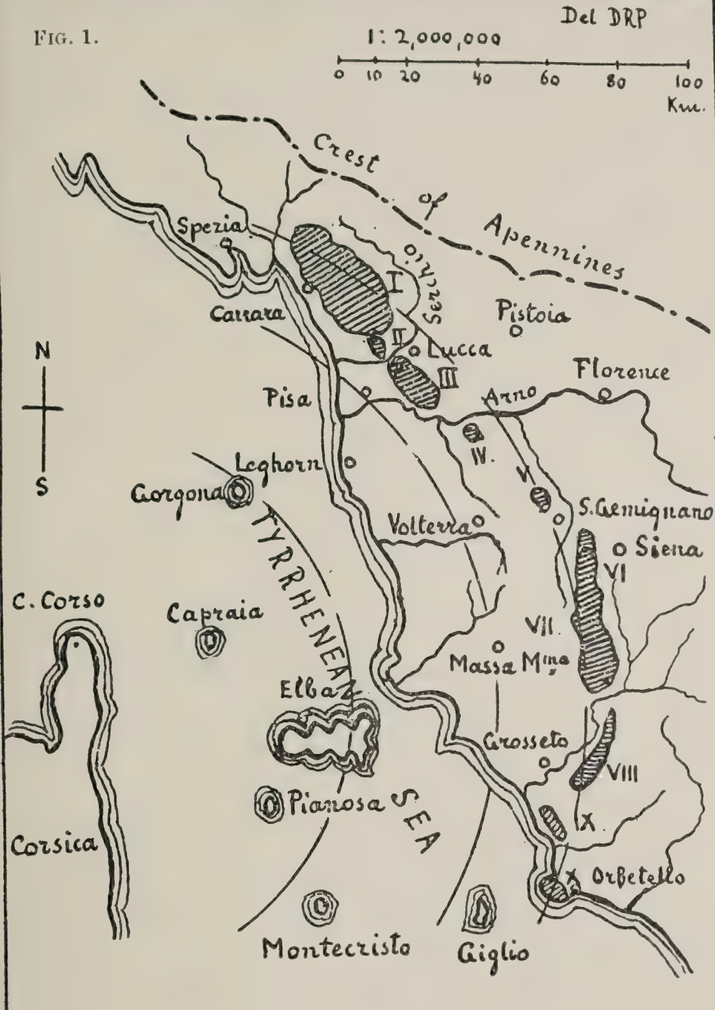
The Triassic series appears in the predominantly Permian part of Monte Pisano only in isolated strips and bands of limestone and calc-schist, between overlying Rhætian limestone and the subjacent verrucano along the base of the massif, e.g. near le Mulina (Caprona) in the southern part ; but a considerable outcrop occurs in the northwestern part under abnormal conditions to be referred to later. Equally rare is the Rhætian which appears in isloated outcrops along the southern base, either associated with Upper Triassic strata as already mentioned, or, in the absence of these, in direct contact with verrucano, e.g. along the south-western base of the massif between the Baths of S. Giuliano, Anciano, Agnano, S. Giovanni alla Vena, and Caprona below Calci. Here, as in the northern part near S. Maria del Giudice, and on the northern side of Mte. Maggiore, Rhætian limestone appears in the same threefold series as in the

[1] The name *Verruca* (Wart) refers to the wart-like appearance of the conglomerate.

[2] L. Busatti, " Turmalinite di Cucigliana " : Proc. Verb. Soc. tosc. Sc. nat., 1887. Also A. d'Achiardi, " Roccc del Verrucano " : ibid., 1892.

The Permian and Trias of the Tuscan Subapennines.

FIG. 1.



I. The Apuan Alps.	VI. Montagnola Senese.
II. Oltre Serchio (Lias).	VII. Monticiano-Roccastrada.
III. Monte Pisano.	VIII. Mte. Orsaio.
IV. Casciana (Lias).	IX. Mte. dell'Uccellina.
V. Jano.	X. Mte. Argentario.

Apuan Alps and also at the base of the Oltre Serchio Hills, viz. : (*a*) the upper, compact, dolomitic, grey and pink, unstratified limestone : (*b*) the middle, dark-grey, fossiliferous, alternating with argillaceous schist ; and (*c*) the lower, cavernous, dolomitic, and sometimes brecciform, unstratified limestone. Of these three, the cavernous limestone is generally the prevalent member ; the upper, grey and pink, includes a subcrystalline yellow variety with calcitic veins and also so-called " portoro " marble, viz. black subcrystalline limestone with yellow veins, such as occurs near Spezia and in the Apuan Alps. In the northern part of Monte Pisano this variety is met with in the Upper Molino glen, and the yellow variety near S. Maria del Giudice below the Lower Liassic white limestone beds.

The Permo-Triassic Displacement of Rupa Cava—Of special interest is the north-western spur of Monte Pisano, which, covering about one-third of the total area, borders on the Serchio defile and forms a triangle between Ripafratta situated in that defile, the Baths of S. Giuliano about 8 km. north of Pisa, and S. Maria del Giudice about the same distance south of Lucca. The old road which connects those places and crosses the pass between them sharply marks the line of division between the main or Permian part of Monte Pisano south-east of that road, and the north-western spur in which the Permian only forms the substratum and is overlain by Triassic, Rhætian, Liassic, and Cretaceous limestones and schists, this secondary series, in which the Lias represents the largest masses, being the eastern extension of that of the Apuan Alps and Oltre Serchio Hills. The complete series of these secondary rocks appears in a section N.W. to S.E. about 5 km. in length from Ripafratta to Mte. Maggiore, Rupa Cava, and S. Lorenzo, which exhibits not only the normal sequence but also reveals a remarkable stratigraphical anomaly due to local displacement.

From the Eocene strata of the Serchio defile [1] at Ripafratta upwards the western flank and the summit of Mte. Maggiore (468 m.) are composed of grey Cretaceous (nummulitic and Neocomian) limestone, followed on the eastern flank by Upper Jurassic (Tithonian) argillaceous limestone and diaspri down towards Rupa Cava. Here the Tithonian abruptly stops, but appears again about 1 km. S.E. Between these two points is wedged an anomalous area of the Permo-Triassic series, viz. of Rhætian cavernous dolomitic limestone, Triassic varicoloured schists, and Permian quartzose conglomerate and sandstone or verrucano. Upon the Tithonian limestone and diaspri which continue beyond, follows the normal white Lias limestone series, then the normal Rhætian cavernous limestone, and lastly a large verrucano mass near S. Lorenzo. The stratigraphical position of the Permo-Triassic wedge and the encasing Tithonian is isoclinal ; the normal sequence of the secondary series is exactly the

[1] B. Lotti, " Geologia della Toscana " : Mem. desc. R. Com. Geol., 1910, p. 380. " Problema stratigrafico Monte Pisano " : Boll. R. Com. Geol., 1888, p. 30 et seq.

same as that of the adjoining Oltre Serchio Hills, which exhibits no stratigraphical anomaly. The section of Mte. Maggiore and Rupa Cava therefore represents a phenomenon peculiar to Monte Pisano and marks a displacement of about 2 km. of Permo-Triassic masses which forced themselves from below as a wedge between and over the Tithonian strata. This interesting phenomenon has been rightly interpreted by Lotti [1] as the effect of a fault produced by the fracture of a retroflex fold during the uprise of the sedimentary formations ; the uprising and consequent pressure continuing, the underlying Permo-Triassic mass was thrust isoclinally along and over the eastern plane of the overlying Tithonian strata. A similar stratigraphical anomaly due to the same cause appears about 1 km. east of Rupa Cava on the road already mentioned over the pass between S. Giuliano and S. Maria del Giudice, where, owing to an inverted fold, Permian schists appear superposed on white Liassic and Rhætian cavernous limestone. The fault here produced obviously coincides with, and extends along the line of contact of the Permian and secondary formations before mentioned.

The Permian Flora of S. Lorenzo.—In the verrucano near S. Lorenzo on the north side of Monte Pisano, at the end of the Mte. Maggiore and Rupa Cava section described above, abundant imprints of fossil flora were found in 1888 by De Stefani and Ristori,[2] the former of whom assigned them, and hence the age of that formation, to the Upper Carboniferous. Soon afterwards, however, the same district, including also the Molino glen, yielded an extremely rich fossil flora to Canavari and De Bosniaski,[3] who referred it decisively to the Permian formation. These organic remains, as Lotti [4] has shown, belong more especially to the lower phyllades which underlie the verrucano quartzose conglomerate, and correspond to others which he himself found in the analogous strata of Mte. Cascetto above Calci in the south-eastern corner of the massif. The Permian age of the predominant Palæozoic part of Monte Pisano was thus conclusively vindicated.[5]

[1] The Eocene strata of the Ripafratta defile contain below the usual albarese limestone and argillaceous schists, macigno sandstone of the highly siliceous or *pietraforte* type, used for paving, as distinct from the less siliceous *pietra serena* which constitutes much of the Florentine macigno and is used more for building purposes. The Eocene sandstone of Ripafratta and Oltre Serchio passes below to nummulitic limestone.

[2] C. De Stefani, "Flora carbonifera Mte. Pisano": Atti Accad. Lincei Roma, 1891.

[3] S. De Bosniaski, "Flora fossile del Verrucano, Mte. Pisano": Proc. Verb. Soc. Tosc. Sc. nat., 1890, 1894. M. Canavari, "Due nuove località di piante fossilifere, Mte. Pisano": ibid., 1891.

[4] B. Lotti, op. cit., p. 13.

[5] In a recent paper, "Il Permiano del Mte. Pisano e i suoi tipi Mesozoici di fossili" (Boll. Soc. geol. ital., 1910, p. 303), Lotti shows that Professor Fucini's opinion of part of the Pisan verrucano being equivalent to the Wealden formation is not founded on fact, the rock in which Fucini's fossils were found not being the true verrucano, but a younger clastic rock or pseudo-verrucano which occurs sporadically among the Mesozoic rocks of Mte. Pisano.

The Permian cupoliform massif is, as previously mentioned, fringed at its base by intermittent Rhætian limestone deposits, except in one part on the north-eastern margin where occurs the isolated Eocene outcrop of S. Ginesio (S. Leonardo) resting direct and transgressively on the Permian. On the other hand, at the base of the western or Ripafratta spur in the Serchio defile, the Eocene overlies normally the Cretaceous and Liassic strata; the total absence of the latter in the eastern part of the massif therefore points to their having been removed by pre-Eocene denudation, unless their disappearance be due to a marginal subsidence in connexion with the low-lying region of Bientina during a more recent period of settlement of the whole massif.

The Mesozoic Group of S. Casciana.—The Upper Triassic, Liassic, and Cretaceous formations of the Ripafratta or western spur of Monte Pisano reappear about 20 km. south of Pisa on the other side of the Arno Valley in the interesting isolated small hilly group of the Baths of S. Casciana, at about 400 m. altitude. The group forms the northern spur of an Eocene ridge between the Era and Tora Valleys, and is, at its base, surrounded by a great Pliocene belt which, together with the Quaternary depression of the Arno, separates it from Monte Pisano and the Oltre Serchio Hills. Its area of about 10 sq. km. comprises in upward succession the following secondary strata: dark grey, compact and brecciform, fossiliferous Rhætian limestone; red and grey Middle Liassic limestone with limonite concretions, and red Tithonian diaspri and Senonian marl with varicoloured argillaceous schists. The S. Casciana group, which forms an anticlinal massif, constitutes the link between the Mesozoic formations of the Oltre Serchio Hills and Monte Pisano on the north and those of the Cecina Valley and Massa Marittima on the south, and as such forms part of the inner, more strictly littoral belt of the metalliferous range or Tuscan Subapennines.

Pliocene and Quaternary Deposits.—The extensive depression of the Arno Valley between Monte Pisano and the hills of S. Casciana, Colle Salvetti, and Leghorn, together with the low-lying regions of Bientina and Fucecchio east of Monte Pisano, reveal some interesting phenomena in relation to the former courses of the Rivers Arno and Serchio. The Quaternary deposits of the low hills of those various regions contain abundant pebbles of verrucano which, derived from Monte Pisano, extend all round north, east, and south of that massif in a radius up to 20 km. These alluvia were obviously transported and deposited before the Arno eroded its present bed along the base of Monte Pisano, that is along the right margin of the valley, when its bed lay more on the southern or Leghorn side of the present littoral plain which at that time was still a shallow estuary. On the south side of the Arno the Pliocene deposits near Pontedera, about 20 km. east of Pisa, contain pebbles of the Apennines and the Apuan Alps, which also occur in the Bientina Hills, here mixed in part with verrucano material. These pebbles could only have been transported

The Permian and Trias of the Tuscan Subapennines.

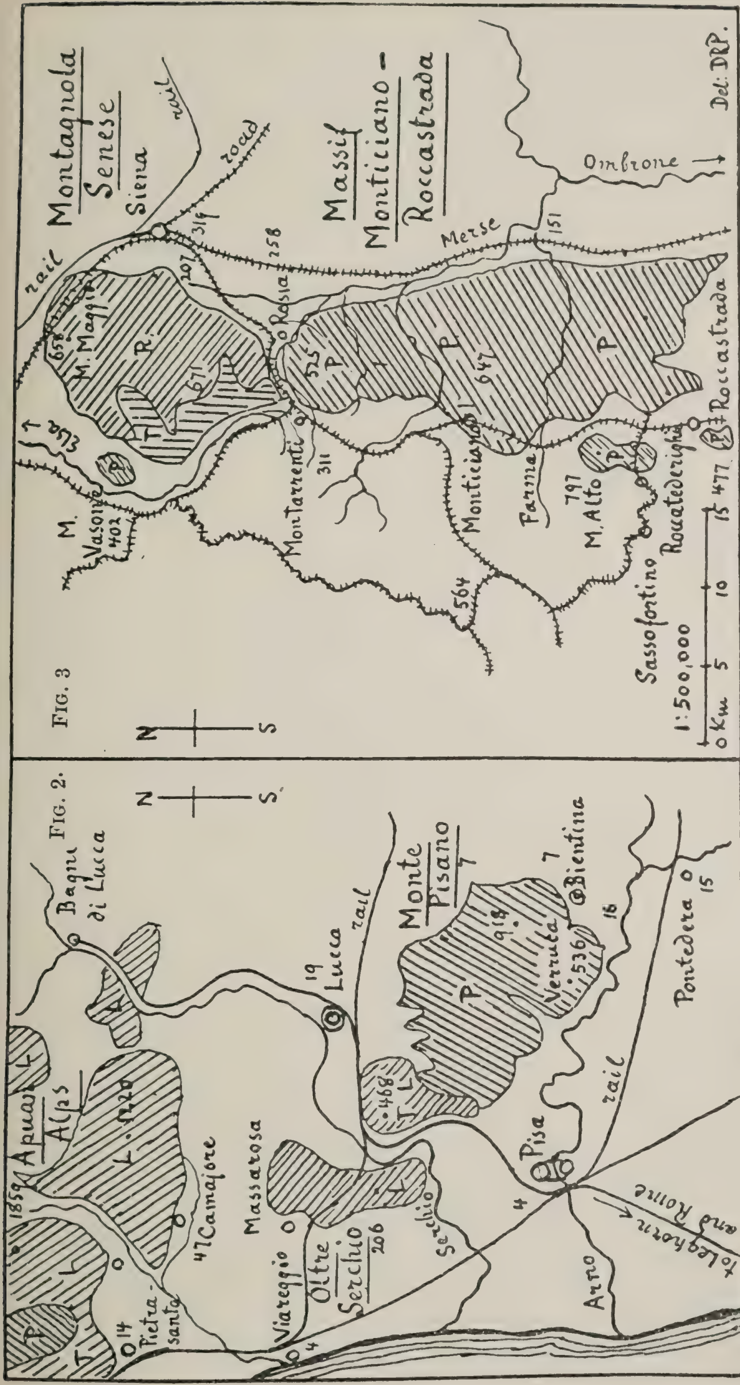


FIG. 2.—Monte Pisano Group.

FIG. 3.—Montagnola Senese and Monticiano-Roccastrada Groups.

P = Permian; T = Trias; R = Rhætian; L = Lias.

by the River Serchio, which in later Pliocene times must therefore have flown from Lucca round the northern and eastern margin of Monte Pisano and discharged into the Arno estuary near Pontedera, until it eroded its present bed from Lucca through the Eocene depression of the Ripafratta defile and thence direct to the sea about 10 km. west of Pisa. Hence the alluvial deposits of exclusively verrucano material around the base of Monte Pisano are obviously posterior to the deflection of the Serchio to its present course, and were formed in early Quaternary times when the actively eroding torrents of that massif could transport and push the Permian material across the Arno estuary and the lacustrine expanses of Bientina and Fucecchio to a distance of 20 km. as already mentioned. The present more northern, meandering course of the lower Arno from Pontedera to Pisa therefore probably dates from more recent Quaternary times, when the Serchio had been deflected, the estuary was gradually receding, and the Arno itself, probably banked by the deposits of the River Era descending from Volterra, was pushed from the southern to the northern margin of the valley. At the same time the two lacustrine expanses of Bientina and Fucecchio, separated by low hills of Pliocene and early Quaternary deposits, were gradually reduced to the present alluvial depressions, their level being slightly above that of the Arno into which their drainage discharges.

The marine, lacustrine, and alluvial deposits of the low hills of the Arno plain or former estuary are of fairly uniform composition. The Pliocene marine deposits which form the lower strata consist of yellow sand and clay with occasional Eocene pebbles, while the overlying Quaternary deposits are composed of more intensely ochre-coloured sand with an upper stratum of exclusively verrucano pebbles and detritus. The transition from the marine to the lacustrine and alluvial deposits is well marked by a constant thin, fossiliferous lacustrine stratum between the fossiliferous Pliocene marine sand, and the Upper Quaternary alluvial (verrucano) deposits. In an interesting exposure on the north side of the Arno between Pontedera and S. Maria in Monte, a fossiliferous lacustrine band appears between the Pliocene fossiliferous marine sand and gravel, thus pointing to a period of oscillation of marine and lacustrine estuary. The clay and yellow sand of the various Quaternary deposits is largely derived from verrucano material, hence with the exception of the Apennine and Apuan material conveyed by the River Serchio before its deflection from the Arno Valley, by far the largest part of the Quaternary deposits of the low hills of that valley is derived from Monte Pisano. Verrucano pebbles are found as far as 20 km. south-east in the low hills near Stagno, close to Leghorn. The same applies to the low hills north-east of the massif, viz. those of Altopascio and Buggiano at the northern ends of the Bientina and Fucecchio depressions, not far from the foot of the Apennines, where Lotti found verrucano pebbles and conglomerate lumps, covered by disintegrated material and fresh quartz detritus of the same origin,

overlying Apennine Eocene material up to over 100 m. altitude.[1] The erosion and denudation of the Monte Pisano massif, as well as the transporting energy of its torrents in a radius of 20 km. all round its base, must therefore have been on a considerable scale both in early and more recent Quaternary times.

II. The Siena Hills. (Figs. 1, p. 107, and 3, p. 111.)

1. *The Montagnola Senese, west of Siena.*

This range of hills lies within a few kilometres west of Siena. It derives its geological interest and importance more especially from its Triassic marble beds which constitute, albeit on a more limited scale, a stratigraphical and lithological replica of the Apuan Alps or Carrara Mountains, while its Permian substratum is a replica of the Monte Pisano formation. In its length, N. to S., of about 30 km. and its width of 15 km. it rises to altitudes of 400 to 700 m., the highest points being Mte. Maggio (658 m.) at its northern end and Poggio di Legni (671 m.) in its western part, or about 250 m. higher than the isolated hill of Pliocene deposits upon which conspicuously stands the city of Siena (319 m.). The range forms, like Monte Pisano, a cupoliform anticline, and lies about midway in the curved Permo-Triassic belt of the Tuscan Subapennines.

The lowest formation of the Montagnola Senese is the Upper Permian or typical verrucano composed, like that of the Pisa Hills, mainly of micaceous and argillaceous varicoloured schists, quartzites, quartzose sandstone, and the characteristic clastic rocks (anagenite) of breccia and conglomerate. In the Apuan Alps, as stated in previous papers, the Upper Permian is only sparsely represented as a transition to the Lower Trias, the predominant substratum there being gneissose rocks of the Lower Permian or Permo-Carboniferous horizon. In the Siena Hills the Permian is overlain by Middle Triassic dolomitic, subcrystalline, dark-grey limestone, in whose granular groundmass are disseminated minute crystals of calcite, the exact equivalent of the fossiliferous grezzoni formation of the Apuan Alps. As in the latter, so also in the Siena range, the grezzoni are overlain by the Upper Triassic marmiferous formation, here composed of crystalline limestone or marble beds with associated subcrystalline and compact limestone, calc-schists, and siliceous schists. The marble beds are, in their turn, overlain by the Rhætian, here stratified series of grey, cavernous, dolomitic limestone, in part crystalline, and fine-grained of white, grey, and pink colour, and sericitic schists passing to so-called pseudo-macigno sandstone, the stratigraphical and strictly conformable sequence being the same as that of the Rhætian of the Apuan Alps and Monte Pisano. The Liassic and Cretaceous formations are not in evidence in the Montagnola Senese, having probably been removed by erosion and denudation, which is moreover attested by the fact that the surrounding Tertiary belt of Eocene,

[1] B. Lotti, op. cit., p. 202.

Miocene, and Pliocene deposits exhibits marked unconformity in relation to the Mesozoic and Palæozoic formations.

The Permian substratum crops out more especially in Mte. Vasone (402 m.) on the north-western margin ; near Tegoia in the central, and also in the Rosia ravine of the southern part of the range, where it adjoins the more extensive and almost entirely Permian massif of Monticiano. The Middle Trias grezzoni and Upper Trias marble beds form the principal outcrops of the western part, while the Rhætian strata, constituting the largest portion of the whole area, occupy the centre and the eastern part which approaches close to Siena. The grezzoni, owing to their distribution in lenticular masses, occasionally thin out, in which cases, e.g. in some small outcrops in the centre, the marble beds rest direct on the Permian. For the rest, as in the Apuan Alps, the substratum is quite separate from the three Triassic horizons closely associated with each other.

The Marble Beds.—The various exposures of the stratigraphical sequence are conveniently accessible from the roads which intersect and flank the Montagnola range. More especially is this the case along the narrow defile of the Rosia torrent already mentioned which cuts the southern part at right angles, and at the western end towards Montarrenti exposes the contact of the Permian with the grezzoni and the Upper Triassic strata. The other principal access is by the road along the Elsa Valley on the western margin of the range, whence various roads lead to the marble quarries in the hills.

One of the largest lenticular masses of marble is that of Montarrenti in the south-western corner of the range near the Rosia road. It extends from Montarrenti north along the flanks of the hills to near Gallena for about 8 km. by 1 km. in width. At Montarrenti the celebrated yellow marble (*giallo* or *broceatello di Siena*) directly underlies the cavernous Rhætian limestone, and is here quarried both as marble of uniform colour and as white, yellow, and pink breccia with veins coloured by iron and manganese infiltrations. Further north the yellow marble passes to white with some intercalations of yellow stratiform marble and violet schists between the principal mass and the overlying Rhætian. At the northern end the marble is quarried above Gallena, on the eastern flanks of the Elsa Valley.

Another large outcrop of marble is that of Marmoraia in the north-western part of the range, at about 550 m. altitude. Here, too, the crystalline formation immediately underlies the Rhætian strata, the former being composed in downward succession of tabular limestone, violet and green, slightly cupriferous schists, and calc-schists in which are embedded lenticular masses of extremely fine statuary marble with associated violet-veined breccia (paonazzo) and bardiglio. The Marmoraia mass extends for about 1 km. to Lucerena, where the yellow marble again predominates and contains abundant though imperfectly preserved Crinoids and Gasteropoda. These and the neighbouring localities of Gioma and Poggio alle Case excel in the

finest varieties of both white and coloured marble, notably green and black, grey-veined, and violet and flesh-coloured breccia. In the central part of the range, at about 500 m. altitude, occur the marble outcrops of Tegoia and Molli, which form similar lenticular masses in the Upper Triassic grey micaceous limestone, violet argillaceous schists, and crystalline calc-schists. Here, too, the marble varies from yellow to white, the latter being often fine-grained statuary, though rather fissile ; the white marble forms the nucleus of the lenticular mass and graduates to yellow towards the periphery.[1]

The Rhætian formation overlying the Upper Marmiferous Trias, although predominantly composed of cavernous dolomitic limestone, contains associated crystalline calcareous masses in which the limestone is fine-granied, white, grey, and pink, the white often exhibiting the characteristic dolomitic pearly lustre, while the pink variety is traversed by calcite veins. These masses occur more especially in the north-western part of the range between Scorgiano and Macellana, north of Marmoraia. The cavernous limestone appears to owe its cavities to the abstraction of carbonate of calcium, the disintegrated residue of which remains in some cavities as a fine grey, sometimes pink powder containing 54 per cent CaO and 43 per cent MgO, whereas the parent rock contains 73 and 22 per cent respectively.[2]

Of the Tertiary formations round the base of the Montagnola, the Eocene appears on the western margin with ophiolithic rocks near Mte. Vasone in Val d'Elsa. The Miocene which overlies the Rhætian limestone on the eastern base of the range near S. Colombo, consists of breccia and conglomerate mainly of cavernous limestone detritus with a yellowish calcareous cement. The Pliocene extends more or less all round the range, more especially towards Siena, which is built on that marine formation, including, in a cliff below the Lizza fort at the northern end of the town, the bright yellow material known as *terra di Siena*, and locally, but improperly, called *tufo* or *puzzolana*.[3] It is simply disintegrated argillaceous schist and in other Pliocene deposits near Siena alternates with grey and blue marl.

The marmiferous formation of the Montagnola was formerly assigned to the Lias, partly on doubtful palæontological grounds, but chiefly because it was assumed to overlie the Rhætian cavernous

[1] According to De Stefani ("Montagnola Senese" : Boll. R. Com. geol., 1879, p. 210) the yellow Siena marble is distinct from the white ; this view is, however, negatived by the white and yellow not only graduating into, but alternating with each other, e.g. in the Montarrenti exposures. The yellow and other colours of marble are obviously due to varying degreés of iron and other hydro-mineral impregnations.

[2] Analysis by Professor Funaro, Leghorn, B. Lotti. "Geologia della Toscana," 1910, p. 40.

[3] The Siena earth is composed mainly of silica and alumina with lime, magnesia, potash, and some iron oxide to which it owes its bright yellow colour. N. Passerini, "Le Sabbie gialle," Firenze, 1903.

limestone.[1] Lotti and Pantanelli,[2] however, proved the reverse to be the true superposition, which was moreover reinforced by Lotti's subsequent discovery of the various outcrops of indubitably Middle Trias grezzoni, which horizon directly overlies the Permian and underlies the marble beds, in strict analogy with the sequence in the Apuan Alps. The equivalence and the Triassic age of the marble beds of both these classic regions were thus clearly and conclusively established.

2. *The Jano and S. Gemignano Hills, N.W. of Siena.* (Fig. 1, p. 107.)

Monte di Jano.—About 30 km. N.W. of the Montagnola Senese, midway between the latter and Monte Pisano, and flanked by the Elsa and Era Valleys, lies the interesting small Permo-Carboniferous and Rhætian group of Monte di Jano at about 500 m. altitude, close to the extensive ophiolithic cluster of Montignoso and S. Vivaldo. The richly fossiliferous Upper Carboniferous or Permo-Carboniferous bed of Jano is the only one in Tuscany proper. Its three outcrops on the south-western flank of the hill are superficially separated by Eocene and Pliocene deposits, and are aligned N.W. to S.E. dipping N.E. and also S.W., thus indicating the original form of a domal anticline. The dark-grey and black bituminous, argillaceous sandstone strata pass upwards to grey, reddish, and violet sandstone and micaceous argillaceous schist; the sandstone strata more especially exhibit conspicuous and extensive veins of cinnabar. The lower bituminous strata contain an abundant fossil flora, the upper sandstone strata a considerable marine fauna, both of which belong to the Permo-Carboniferous transition horizon.[3] Upon these strata rests conformably the Permian series composed in upward succession of violet, arenaceous, tegular schists, sandstone, quartzite and verrucano conglomerate with intermediate schistose alternations, the Permian rocks being on the whole of a paler grey, violet, and green colour than the underlying Permo-Carboniferous strata. As in Monte Pisano, so also in the Jano group the Trias proper is absent, the Permian being directly overlain by Rhætian dark-grey, more or less crystalline, in places brecciform limestone. A peculiar feature of the latter is the conspicuously reticular form of infiltrations of iron oxide, which, combined with disintegrated detritus of limestone, has

[1] C. De Stefani, op. cit., 1879–80. A. Fucini, "Età del marmo giallo di Siena": Atti Soc. Tosc. Sc. nat., 1903.

[2] D. Pantanelli & B. Lotti, "Sui marmi della Mont. Sen.": Boll. R. Com. geol., 1878, p. 384. B. Lotti, "Nuove osservazioni Mont. Sen.": ibid., 1888, p. 341. Op. cit., 1910, p. 34. A. Verri & E. Clerici, "Mont. Sen.": Boll. Soc. geol. ital., 1903, pp. lxxix, 2.

[3] The fossil flora and fauna of the Jano district, which latter is easily reached from Castelfiorentino in the Elsa Valley, studied as early as 1850 by Savi and Meneghini, has more recently been dealt with by G. Arcangeli, "Due fossili di Jano": Boll. Soc. bot. ital., 1896, and L. Barsanti, "Flora fossile di Jano": Mem. Soc. Tos. Sc. nat., 1903, 1904; also B. Lotti, op. cit., p. 6.

produced a considerable formation of red earth or "terra rossa", by a local misnomer also called pozzolana. The Jano group constitutes an isolated outcrop in a Miocene and Eocene northern spur of the Siena Hills, surrounded by a great Pliocene marine belt which extends north to the Arno Valley.

S. Gemignano Hills.—This Rhætian group lies south-east of Jano and is more especially developed in the hill called Poggio del Comune above S. Gemignano, at 624 m. altitude on the divide between the Elsa and Era watersheds. The outcrop, about 10 by 3 km. in length and width and surrounded by Miocene and Pliocene deposits, is aligned on the same axis with the Jano group N.W. and the Montagnola Senese S.E., from which latter it is separated by the Pliocene and Quaternary depression of Colle Val d'Elsa (223 m.). The dolomitic, cavernous, compact, and also brecciform dark-grey Rhætian limestone of this locality is exactly like that of the two neighbouring groups, as also like that of Monte Pisano. It exhibits here and there at different levels considerable intercalated masses of gypsum often stratified, traversed by grey veins, and including limestone fragments. Although Rhætian limestone is the favourite seat of gypsum in various parts of the Tuscan Subapennines, the latter occurs also in Triassic, Liassic, Cretaceous, and even in Eocene and Miocene limestone beds, and therefore irrespective of age in any calcareous rock whose carbonate of lime is transformed to sulphate by hydro-mineral action, preferably near the contact of the limestone with other horizons.

3. *The Monticiano and Roccastrada Hills, south of Siena.* (Fig. 1, p. 107; Fig. 3, p. 111.)

This considerable area constitutes the southern extension of the Montagnola Senese, which it adjoins at the transverse line of division formed by the Rosia torrent between Montarrenti on the west and the village of Rosia on the east. The Permian series which appears on both sides of that defile continues south at about 500 m. altitude uninterruptedly across the Merse ravine to Monticiano and Mte. Quoio, the highest central point (647 m.), and thence across the Frama ravine to Mte. Alto (797 m.) and Roccastrada (477 m.) at the southern extremity. The Permian sequence is substantially the same as in the Montagnola Senese and Monte Pisano. In a considerable exposure near Roccastrada it exhibits banks of conspicuously white and pink quartz with a lustrous white micaceous cement and fragments of violet and green schists. The associated arenaceous and phylladic schists of this exposure are greatly folded and contorted, and similar contortions appear on the margin of the north-western part of the massif near the Merse torrent between Monticiano and Pentolina. The laminated greenish schists show marked evidence of crushing, although they contain cavities with large crystals of pyrite which exhibit no trace of disturbance and are therefore a secondary phenomenon, posterior to the lamination

of the schists. The verrucano conglomerate of the massif is frequently traversed by oligist veins.

In the whole massif Triassic outcrops are rare and sporadic, a notable though small mass being that near Pari on the eastern margin where Novarese found abundant characteristic Triassic fossils (Crinoids and Gasteropoda) in a black limestone with felspathic veins.[1] On the south-western margin near Roccastrada at the base of Mte. Alto, a bed of subcrystalline Triassic limestone appears between the overlying Rhætian and the subjacent verrucano schist and conglomerate. Rhætian, prevalently cavernous dolomitic limestone appears in small outcrops not only all round the Permian area but also in the centre of the massif and near Mte. Alto, frequently with gypsum intercalations. Of the latter a large mass occurs in the Rhætian dark limestone near Roccastrada with fragments of the encasing rock, the transformation from carbonate to sulphate of lime extending also to the underlying Triassic, more schistose limestone.

The Monticiano–Roccastrada massif, covering an area of 30 by 10 km., viz. as large as that of Mte. Pisano, forms, like the more northern groups, a cupoliform anticline, and is at its base surrounded by Tertiary deposits of which the Eocene on the eastern margin comprises the ophiolithic group of Murlo, and on the west some similar masses near Sassofortino and Montemassi, while in the Miocene deposits close by, viz. round the base of Mte. Alto, appear the trachytic groups of Roccatederighi and Roccastrada. Small isolated Permian, Triassic, and Rhætian outcrops occur east of the Monticiano massif near Massa Marittina and Boccheggiano which form part of the inner, littoral, predominantly Tertiary belt of the Tuscan Subapennines.

III. The Grosseto (Maremma) Hills. (Fig. 1, p. 107.)

These, the most southern groups of the Permo-Triassic belt, comprise the cupoliform anticlines of Mte. Orsaio north-east of Grosseto, of Mte. dell' Uccellina, and of Mte. Argentario on the Tyrrhenean coast south of that town, which lies in the Quaternary plain of the lower Ombrone Valley surrounded by the Maremma Hills.

The Monte Orsaio Group is the southern continuation of the Monticiano–Roccastrada massif, from which it is separated by the Miocene and Pliocene depression of the Ombrone Valley. The latter circumscribes it on the east, the Quaternary plain of Grosseto on the south and west. Its area is 15 by 10 km., or about half that of its northern neighbour ; in altitude it varies from 300 to 600 m., the highest point being Mte. Leone (614 m.) in the centre. The Permian comprises the same series as in the other groups described, and the same applies to the overlying Rhætian, which forms a number of

[1] V. Novarese, " Fossili triassici nei monti della Maremma Toscana " : Boll. Soc. geol. ital., 1894, p. 15.

isolated deposits, prevalently of cavernous limestone, both on the periphery and in the centre of the Permian massif. The Trias proper is represented only by one deposit of varicoloured schists between the Permian and the Rhætian near Montepascoli on the south-western margin. The Mte. Orsaio massif obviously became separated from its northern neighbour by the erosion of the intervening syncline, now the Ombrone Valley.

The Monte dell' Uccellina Group lies on, and parallel to the coast about 10 km. south of Grosseto between the mouth of the River Ombrone and that of the Albegna. In its length and width of 15 by 5 km. it rises to an altitude of over 400 m., and forms an elongated rectangle composed of the Permian series in the south-western and of the Rhætian in other parts, overlain in the north by Liassic deposits. On the eastern side the group is flanked by a Pliocene and Quaternary depression which separates it from the large Eocene area of Mte. Cornuto.

The Monte Argentario Peninsula near Orbetello, about 15 km. south of the preceding group, is an interesting oval-shaped massif 10 by 5 km., rising to 635 m. altitude, in which considerable Permian outcrops appear in the southern part, while the overlying Trias forms a number of isolated deposits scattered over the peninsula, notably on the west coast. More especially on the coast between Calagrande and Isola Rossa, and in the Calagrande glen, the Trias is composed of crystalline limestone, calc-schists, phyllades, and dark-grey and violet sericitic schists with intercalations of saccharoidal marble and associated ophiolithic rocks, which include serpentine, euphotide, and diabase with amphibolic and prasinitic rocks,[1] alternating with the sedimentary schists. Upon the Trias rests in various parts of the peninsula the usual Rhætian cavernous dolomitic limestone which in one part of the coast contains a considerable mass of gypsum and in another part a ferro-manganese deposit. On the neighbouring mainland the Permian and Rhætian also form the considerable areas of Poggio Venti (341 m.), Monteti (435 m.), and Mte. Bellino (516 m.), known as the Capalbio Hills, which constitute the south-western extremity of the Tuscan Subapennines between the sea and the great volcanic region of Bolsena.

IV. Conclusion. (Fig. 1, p. 107.)

The Permian formation of the Tuscan Subapennines, forming a belt of over 200 km. in length, constitutes the middle part of the great Permian chain which in the north extends from the Maritime Alps to Western Liguria and the Apuan Alps, and in the south reappears in Calabria and Sicily. Its course is thus more or less continuous and parallel to the Mediterranean coast throughout the entire length of the Italian Continent. Its greater age and

[1] S. Franchi, "Prasiniti ed anfiboliti di Pegli, Giglio, Gorgona e Mte. Argentario": Boll. Soc. geol. ital., 1896, pp. 8, 169.

independent geological history as compared with the predominantly Eocene Apennines is emphasized by the fact that the axis of the latter, more especially of the Etruscan Apennines, conforms, not to the Mediterranean, but essentially to the Adriatic coast. The Permian and Triassic outer belt as well as the inner, predominantly Tertiary belt of the Tuscan Subapennines exhibit a general inclination and fall of altitude towards the Tyrrhenean Sea, along whose coastline the Pliocene marine deposits have been submerged and the existing headlands abruptly plunge into the sea to a depth of 100 metres, which in the Tuscan archipelago increases to 200 metres. These two belts, together with that of the Tuscan archipelago, form, in fact, three concentric zonal fold-curves as intimately associated with the Mediterranean as the Apennines are with the Adriatic. The three fold-curves (dotted lines, Fig. 1, p. 107), which have their common thrust-centre in the northern extremity of Corsica, at distances of 110, 160, and 180 km. respectively, mark the zonal alignment not only of the repeated Tertiary uprise but of the Post-Pliocene subsidence and settlement of the three belts. Of these the outer or Permo-Triassic belt had already emerged as a series of low anticlines and synclines before the great general uprise in early Miocene times. The Post-Pliocene or most recent subsidence which submerged the Pliocene marine deposits, is computed at a minimum of 200 metres both as regards the mainland and the archipelago, where the lowest submarine contour corresponds to that depth. But west of the archipelago towards Corsica the submarine contours drop to 500 and 600 metres [1]; hence the actual subsidence was probably in excess of the estimate. In any case the present archipelago represents the subaerial part of the submerged and broken-up Tyrrhenean Continent which in later Miocene times connected the central Mediterranean group of Corsica and Sardinia with the Italian Peninsula.

According to the overthrust theory, the Permian, Triassic, and Liassic groups of the Tuscan Subapennines represent so many " windows " or " Fensterklippen " of exotic origin.[2] But the stratigraphical evidence and essentially conformable superposition of those formations is adverse to that hypothesis, for it clearly shows that all those sedimentary series were formed in situ; that the only attested displacement by overthrust on the mainland is the purely local and partial one in Monte Pisano; and that the Palæozoic and Mesozoic formations of Tuscany are the " rooted " equivalents of those along the Mediterranean coast in Northern and Southern Italy.

[1] On the west coast of Elba, towards Corsica, the submarine contours drop at first rapidly to 75 m. in 500 m., equal to 150 m. per km.; then slope more gradually to 600 m. in 24 km., or 40 m. per km.

[2] G. Steinmann, " Alpen und Apennin ": Mon. B. D. Geol. Ges., 1907, p. 177.

XII.

The Ophiolithic Groups of the Tuscan Subapennines.

Introductory.

THE region in which lie the ophiolithic groups to be considered in these pages embraces not only the western part of Tuscany but also the northern outskirts of the Apuan Alps or Carrara Mountains, which latter form the link between Liguria and Tuscany proper. From the numerous metalliferous deposits scattered throughout its area, the region is geologically and comprehensively known as the *Catena Metallifera*, and as such extends N.W. to S.E. parallel to the Tyrrhenean coast from the Hills of Spezia down to those of Grosseto and Monte Argentario.[1] In its total length of about 200 km. and 70 km. in greatest width it is composed of two approximately concentric zones ; an outer one, whose axis and substratum is formed by the series of Permian, more of less cupoliform anticlines of the Apuan Alps and the Hills of Pisa, Siena, and Grosseto,[2] and an inner, more strictly littoral, and predominantly Tertiary zone which comprises the Hills of Leghorn, of the Cecina Valley, and of Massa Marittima. By extension the region also includes Elba with its mineral wealth and the other islands of the Tuscan archipelago, which are, however, outside the scope of the present paper. On the mainland the metalliferous range is distinguished by great diversity of geological features, structure, and composition from the Palæozoic to the Mesozoic and Tertiary formations, the latter with a remarkable series of ophiolithic groups. It offers in this respect a great and fundamental contrast to the monotonously uniform sedimentary Eocene of the Etruscan Apennines, and although geographically considered an offshoot of the latter, it is geologically an older and therefore independent range. The ophiolithic groups lie, as regards the mainland, all in the Lower Tertiary horizon of Upper Eocene limestone and argillaceous schists, the principal groups being those of :—

I. The Apuan Alps.
II. The Leghorn Hills.
III. The Cecina Valley.
IV. The Hills West, North, and South of Siena.[3]

[1] The best general geological map of Tuscany is B. Lotti's survey-map 1 : 500,000 attached to his "Geologia della Toscana" : Mem. descr. R. Com. geol., 1910, the latter founded in part on his previous memoirs.

[2] *Vide* the preceding paper, "The Permian and Triassic Belt of the Tuscan Subapennines."

[3] The small ophiolithic groups of Prato and Impruneta near Florence, and of the upper Tiber Valley near Borgo San Sepolcro, composed mainly of serpentine, euphotide, and diabase, belong to the Apennines proper and are not included in the present paper. The extensive and remarkable groups of Elba are dealt with in the paper No. XIV on that island.

I. The Groups of the Apuan Alps. (Fig. 1.)

This region, which in relation to its great Triassic Marble formation was described in a previous paper,[1] is skirted on the north by the three ophiolithic groups of the Sarzana, Lunigiana, and Garfagnana districts. The small Sarzana group, about 10 km. from the coast, midway between Spezia and Carrara, on the left of the River Magra, is composed chiefly of peridotitic rock largely altered to bastitic serpentine, which alternates with the "ranochiaia" (green and yellow with black veins) variety and olivinic euphotide. It forms the link between the Pignone and Levanto groups of Eastern Liguria west of Spezia described in a previous paper,[2] and the groups of Lunigiana and Garfagnana. The Lunigiana group, near Aulla and Bibola, about 15 km. north of Sarzana, consists mainly of diabasic masses with an outcrop of associated granite near Tresana.

The Ophiolithic Groups of the Apuan Alps. Sketch-map.

Fig. 1.—Sarzana, Lunigiana, and Garfagnana Groups.

The most extensive of the three groups is that of the Garfagnana district in the Upper Serchio Valley, which is reached either from the south, viz. from Lucca and Castelnuovo, or from the north, viz. from Sarzana or Aulla up the Aulella Valley to Fivizzano and thence over the Carpinelli Pass (835 m.) or saddle between the Apuan Alps and the Etruscan Apennines. It is in this latter synclinal depression, and more especially on the southern or Garfagnana side, that the principal ophiolithic masses crop out in the remarkable gorge eroded by the Serchio and its affluents the Gragnana, Sambuca, and Mozzanella torrents, as well as at higher levels between Piazza

[1] "The Carrara, Massa, and Versilia Marble District," Part I of this volume.
[2] "The Ophiolithic Groups of the Ligurian Apennines," Part I of this volume.

(500 m.), Camporgiano (478 m.), Roccalberti, and Poggio, where the road, in a distance of about 15 km., skirts the lower spur of Mte. Pisanino (1948 m.), the highest point of the Apuan Alps, on one side and the Serchio gorge on the other.

The ophiolithic masses appear principally on the right, to a small extent also on the left of the Serchio, which has eroded its bed down to the Eocene sedimentary strata. The normal sequence of the latter is reversed in the road-section already mentioned, owing to an inverted fold in the synclinal depression, the strata of the Apuan side having been thrust against those of the Apennine side of the valley, so that the ophiolithic rocks appear in that part of the gorge below instead of above the Upper Eocene albarese limestone and argillaceous schists or galestri, and abnormally overlie the Middle Eocene macigno sandstone exposed in the river bed as the substratum.[1]

The ophiolithic rocks, more especially at the higher levels, are prevalently peridotitic serpentine, olivinic euphotide, and diabase, with which, as in the Aulla group, is associated typical granite, notably in the outcrops of Piazza, Camporgiano, Bosco di Villa in the Mozzanella, as also in the Sambuca and Gragnana ravines. The granite, which generally overlies the serpentine with intermediate strips of diabase and also appears lenticularly in both these basic rocks, is fine-grained and exhibits felspar (orthoclase and albite), biotite largely altered to chlorite, and subordinate quartz abounding in liquid inclusions and showing evidence of crushing.[2] The serpentine appears in the normal, the lustrous and laminated, and also in the ranochiaia varieties, and generally constitutes the lowest member of the eruptive series. The diabasic masses in the different localities are in part well preserved, both aphanitic and porphyritic with diallage, in part altered to chloritic and amphibolic prasinites, frequently also of spheroidal and variolitic structure, and occasionally exhibiting euphotide veins, though the last-named rock is comparatively subordinate in the whole area. A notable diabasic variety is the yellow and red rock formerly called *gabbro rosso* and vaguely regarded as metamorphic sedimentary, like the subcrystalline, silicocalcareous, indurated diaspri ; it is, however, simply altered diabase, whose colour varies according to the degree of hydration and oxidation by atmospheric action. Hence it occurs generally in the upper superficial parts of normally dark-green diabase masses. The misleading term of *gabbro rosso* has been entirely discarded.

Although the various isolated ophiolithic, predominantly diabasic outcrops of the Garfagnana group are here and there overlain by

[1] This inverted fold was first pointed out by C. De Stefani, "Roccie serpentinose della Garfagnana": Boll. R. Com., 1876, p. 16 et seq. "Serpentine e graniti dell' alta Garfagnana": ibid., 1878, p. 19 et seq.

[2] Some of the Garfagnana and Aulla rocks were also examined microscopically by P. Aloisi. "Studio petrografico delle Alpi Apuane (roccie granitiche ed ofiolitiche)": Boll. R. Com., 1905, p. 257 et seq. The crystalline rocks of the Marble District proper were mircoscopically examined by E. Mattirolo and S. Franchi, some also by Professor d'Achiardi of Pisa.

rocks more recent than the Upper Eocene, they are, owing to the removal of the less resistant sedimentary strata by erosion and denudation, collectively so well exposed that they convey an excellent idea of a formerly considerable and continuous area of eruptive rocks, of which the breccia and conglomerates of eruptive and sedimentary material on the outskirts afford additional and conclusive evidence. The three ophiolithic groups of Sarzana, Lunigiana, and Garfagnana thus form, in a total length of 50 km., a more or less continuous semicircular belt round the northern base of the Apuan Alps and lie in a zone with the coeval Eocene groups of Eastern Liguria.

II. The Groups of the Leghorn Hills. (Fig. 2, p. 127.)

The Hills of Leghorn, rising to 300 and 450 m. altitude, comprise a number of scattered ophiolithic masses which in the aggregate cover about 50 square km., the most notable being those of Gabbro on the divide east of Mte. Nero, a well-known and prominent point south-east of the town, and of Romito, Castiglioncello, and Rosignano on or near the coast about 15 km. south of the same.

1. The ophiolithic mass of *Gabbro*, a village which derives its name from the Tuscan vernacular term indiscriminately used for serpentine and euphotide,[1] is composed of a nucleus of lherzolitic serpentine fringed by euphotide, on which latter the village itself is built. The serpentine is often diallagic and also schistose, while the euphotide is in many places altered to steatite. At the contact of the two rocks with the surrounding Eocene limestone, galestri, and dark-red diaspri, the latter in several places form a conglomerate with pebbles of steatite derived from the decomposed eruptive rocks. The euphotide overlies, and forms veins in the serpentine; near the summit of Mte. Caprona it is replaced by the hypersthenic variety with an associated fine-grained granitic rock.[2] The area includes the heights of Poggio Gabbruccio, Mte. Maggiore, and Mte. Corbolone, and is easily accessible by various roads along which interesting exposures may be studied.

2. About 10 km. south of Leghorn, near the coastal road and railway, juts out the interesting, rocky, and barren headland of *Torre Romito*, composed of euphotide which, with red diaspri, is interposed between albarese limestone and galestri schists resting on macigno sandstone which also constitutes the twin outcrop of Torre Calafuria. The euphotide, traversed by diabase veins, is greatly altered to serpentinous schist exhibiting, more especially in the lower parts, secondary epidote, chlorite, and calcite, with which latter it is also

[1] The promiscuous use of the term gabbro for rocks, hills, and villages in Tuscany has led to its being generally discarded and replaced by euphotide, as referring to the younger and altered gabbric rocks. Gabbro is restricted to the older unaltered, essentially felspathic rocks. *Vide* Part I, p. 26.

[2] For microscopic details of these rocks *vide* L. Busatti, "Studi petrografici": Proc. Verb. Soc. Tosc. Sc. nat., 1887, and E. Manasse, "Roccie ofiolitiche dei Monti Livornesi": ibid., Atti, 1898, p. 21.

veined. The diabase is largely uralitized to chloritic prasinite ; the hypersthenic variety of euphotide is also met with. The Romito mass is connected with several similar outcrops of euphotide on the flank of Mte. Nero, facing the sea.

3. About 5 km. south of Torre Romito lies the headland of *Castiglioncello*, largely composed of altered euphotide, immediately north of which, along the coast-road, occur the extensive serpentine masses of Mte. Pelato (378 m.) and Mte. Carvoli with subordinate associated euphotide, both of which rocks exhibit veins of siliceous, chalcedonic concretions and are overlain by Miocene limestone. A few kilometres east of this mass crops out that of *Rosignano* in the Fine Valley, in which euphotide and diabase largely predominate, while serpentine, notably the porphyritic diallagic type with diabase veins, as also the ranochiaia variety, only appear in one locality near Poggio Berna (147 m.). This hill is composed of both spheroidal and porphyritic diabase in which are lenticularly intercalated small masses of ranochiaia serpentine, the contact of the two rocks being marked by films of asbestos with cupriferous efflorescences. Further along the same road it is euphotide, which is similarly intercalated in diabase with large diallage crystals, the contact line being perfectly distinct ; similarly, porphyritic diabase appears intercalated in the normal, compact diabase.[1]

III. The Groups of the Cecina Valley. (Fig. 2, p. 127.)

The most extensive ophiolithic masses of Tuscany occur in the upper hills on both sides of this valley or basin, which is also noted for its metalliferous deposits, the *soffioni* or boracic steam jets of Larderello, and the salt pits of Saline below Volterra. The ophiolithic masses on the right or north side of the River Cecina begin about 8 km. east of the coast-town of that name, or about 30 km. south of Leghorn, and comprise from west to east in an area of about 150 sq. km. the groups of Castellina, Riparbella, Terriccio, and Montecatini. Those on the left or south side of the valley, on the other hand, comprise the groups of Bolgheri, Monterufoli, Montecerboli, and Montecastelli, which cover about 300 sq. km. All these groups lie in the surrounding Eocene sedimentary horizon, which in its turn is circumscribed by a region of low hills of Miocene and Pliocene deposits reaching down to the River Cecina.

1. *On the Right of the Cecina.* (Fig. 2.)

(1) *The Castellina Groups.*—The most northern mass is that of Mte. Vaso (584 m.), predominantly composed of lherzolitic serpentine traversed by large veins of euphotide and diabase. The same rock is the principal constituent of the two masses of Riparbella, including Mte. Vitalba (674 m.), and of Terriccio, a short distance to the west, but with more euphotide and diabase, the order of superposition

[1] The euphotide of Castiglioncello has been also described by R. Ugolini, Boll. Soc. geol. ital., 1905, p. 71.

being as usual. Here and there the diabase, as the uppermost member, is overlain by albarese limestone with red diaspri, the serpentine, on the other hand, by galestri schists. The diabase is often altered to chloritic prasinite with marked spheroidal structure, e.g. at Castellina, which is built on a boss of that rock. Between Castellina and Riparbella the diallagic serpentine is traversed by considerable veins of porphyritic diabase, which along the road between those two places also occur in the ranochiaia serpentine. Further on, at Pescine, a cupriferous deposit occurs in an aggregation of porphyritic diabase, euphotide, and steatitic rock derived from both. The Terriccio mass is, besides diabase and serpentine, largely composed of euphotide, in which, near the contact with diabase, occurs a cupriferous deposit, the euphotide being here intercalated in diabase. These deposits are, however, only of very limited extent.

(2) *The Montecatini Group.*—East of the Castellina groups occurs the cluster of ophiolithic masses of Montecatini. Near the well-known copper-mine of that locality, the only really important one in Tuscany, two masses of diabase, one of Mte. Massi (609 m.) and the other of Poggio alla Croce, are separated by a narrow sedimentary band, while other masses, notably those of Mte. Vignoli, Miemo, and Orciatico, appear in the same Eocene strata a little further west. In these masses diabase is largely predominant with subordinate serpentine and euphotide, of which the latter more especially is so decomposed to steatite that hardly a trace of the original rock is left and the overlying diabase seems to rest direct on the serpentine. This steatite, chiefly derived from decomposed saussuritic felspar, occurs, as it does in the Leghorn Hills, also intercalated in the diallagic serpentine and often contains small cupriferous deposits.

In the diabasic masses of the Montecatini mine euphotide and serpentine only appear underground, underlying the diabase in the usual order. The latter is largely spheroidal with unaltered nuclei, and also variolitic, of normally dark green, but where altered, of reddish colour (*gabbro rosso*), passing externally to a green, chloritic steatitic product of decomposition, the most advanced stage of the latter being a clayey, ferruginous material. These last stages appear more especially at the contact with the cupriferous deposits. At one point of the mine, at a depth of 100 m. below the surface, a serpentine mass envelops a lenticular mass of nodulous euphotide in part diallagic, in part serpentinized, while at another point of considerable depth a mass of lherzolitic serpentine appears close to the diabase intercalated in Eocene galestri schists. The lherzolitic serpentine masses of Miemo and Orciatico are also overlain by euphotide and diabase with associated ophicalce. The diabase of Mte. Vignoli is in part coarse-grained and unaltered, with large elements of labradorite and pyroxene, in part fine-grained and altered to reddish brown with small radially disposed amygdaloids of calcite, or again, with cavities

The Ophiolithic Groups of the Tuscan Subapennines. Sketch-map.

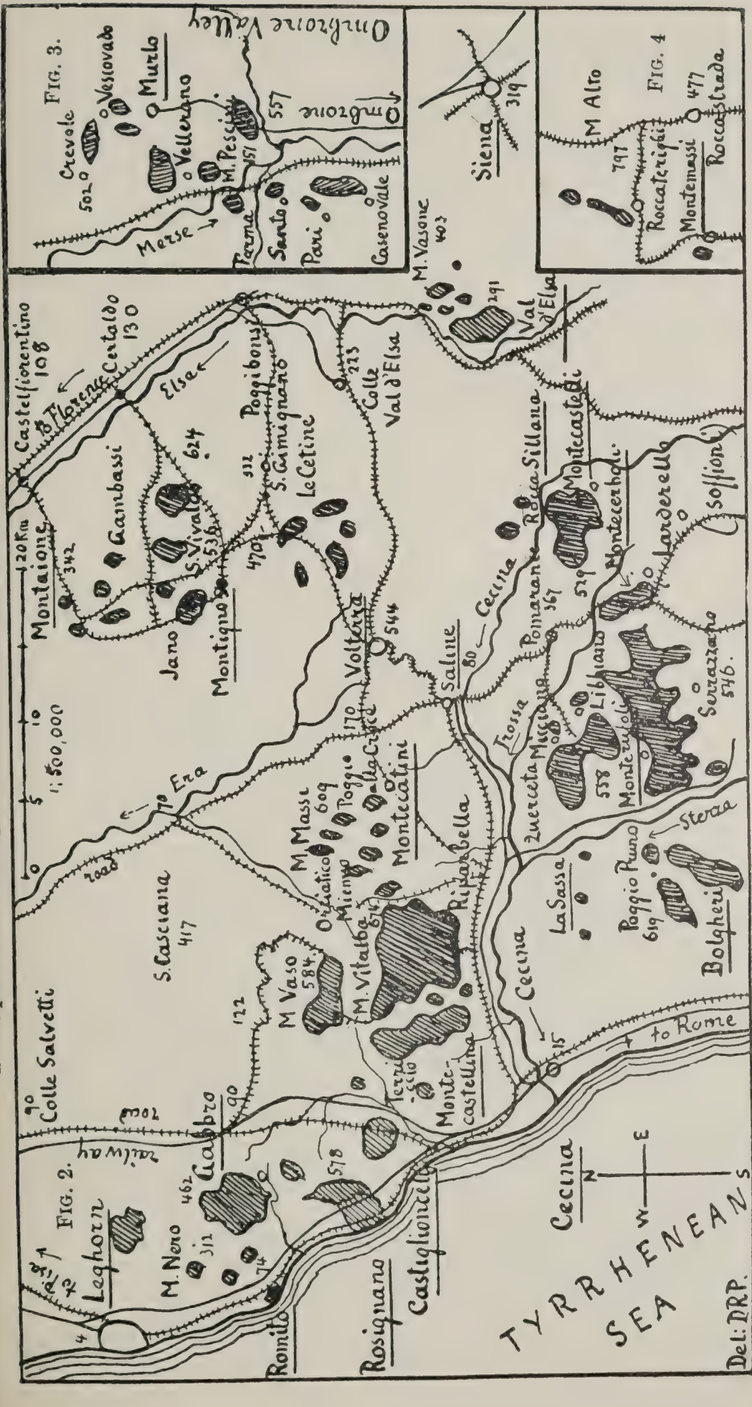


Fig. 2.—The Leghorn Hills, Cecina Valley, Val d'Elsa, and Montaione Groups.
Fig. 3.—The Murlo Group. Fig. 4.—The Montemassi Group. (S. of Siena.)

from which the calcite has disappeared.[1] The globular metalliferous deposits of Montecatini, in the main calcopyrite and erubescite, are generally encased in the steatitic matrix or *losima* already mentioned ; more rarely aggregations appear in only partially altered and decomposed euphotide, as also in a felspathic, quartzose, and chalcedonic breccia. The cupriferous deposits of the two diabase masses of Mte. Massi and Poggio alla Croce already mentioned occur separately in lenticular steatitic intercalations both in the diabase itself, and between diabase and the sedimentary strata, the matrix being derived from diabase, or again, in the largest deposit, from euphotide. The Miemo deposit appears at the contact of serpentine and diabase in a mass of amygdaloidal, olivinic serpentinized euphotide. In the sedimentary strata there is no evidence of intrusion by dykes or apophyses or of contact metamorphism ; the ophiolithic groups are essentially lenticular masses interposed in those strata when these were still in a plastic condition. Occasionally simulated intrusions in the latter are, as Lotti has pointed out,[2] the result of local shifting of the ophiolithic and sedimentary masses by earth movements posterior to their formation.

2. *On the Left of the Cecina.* (Fig. 2, p. 127.)

(1) *The Bolgheri Group.*—The four masses which compose this group and lie in the Eocene of Poggio Pruno, a hill of 618 m. altitude between the coast and the Sterza torrent, an affluent of the Cecina, consist mainly of lherzolitic serpentine with euphotide and diabase, of which the former is to a small extent metalliferous. Much of the serpentine is of the ranochiaia type with veins of yellow resinite ; with the euphotide and the prevalently porphyritic diabase are often associated red diaspri overlain by Eocene limestone and galestri schists.

A remarkable phenomenon in this group is the large calcitic and ophiolithic band of La Sassa on the left of the Sterza torrent about 10 km. from the junction of the latter with the Cecina. This band, which near La Sassa reaches 50 m. in thickness, runs through the Eocene sedimentary strata for about 2 km. N.W. to S.E. and is composed of calcite and quartz concretions with disseminated minute pyrite crystals and with cavities containing a bright green mineral, the mass itself being reddened by impregnations of iron. Near La Sassa, whose castle is built on this band, the mass is calciferous with empty cavities, and is traversed by large veins of pure-white calcite, while parallel to, and midway in the band runs a vein of steatite with fibres of asbestos. At its southern end the band expands to a mass of compact quartz with pyrite crystals and the

[1] These calciferous, amygdaloidal, and cavernous forms of diabase correspond respectively to the borzolite and coschinolite of Liguria, mentioned in a previous paper, Part I of this volume.

[2] Op. cit., p. 234.

green disseminated mineral already mentioned, in contact with a metalliferous mass of euphotide. The steatite and the green mineral are obviously products of ophiolithic decomposition, while the quartzose and calcite band itself is the result of opaline silicification, like resinite and chalcedony.

(2) *The Monterufoli Group.*—This, the largest of the ophiolithic areas of the Cecina Valley, lies between the Sterza and Trossa torrents and comprises the masses of Querceta, Micciano, Libbiano, Serrazzano, Monterufoli, and Montecerboli, at average altitudes of 550 m. Of the two last-named localities, Monterufoli is noted for its lignite mine on the western margin of the ophiolithic area, while Montecerboli is contiguous to the large area of the well-known boracic steam jets of Larderello, Monterotondo, and Castelnuovo on the divide between the Cecina and Cernio Valleys. The predominant ophiolithic rock of the Monterufoli area collectively is lherzolitic serpentine, which forms a cupoliform massif no less than 60 km. in circumference, overlain here and there by Eocene sedimentary rocks and on its margin by small masses of euphotide and diabase with red diaspri. The euphotide mass near the lignite mine is traversed by veins of siliceous concretions which yield beautifully tinted and much-prized chalcedony, also cemented with serpentine and asbestos fragments to a very delicate breccia. At another point in the vicinity occurs a resinitic mass derived from euphotide, the felspar being here by the same process of opalization transformed to opaline silica. In this locality the ophiolithic rocks are metalliferous, small cupriferous aggregations being met with in steatitized euphotide veins traversing the serpentine. In the Querceta or Mte. Anéo area too the euphotide is slightly metalliferous, the serpentine being here traversed by veins both of euphotide and porphyroid diabase.

Of special interest are the two predominantly diabasic masses on which are built the villages of Micciano and Libbiano, separated by a depression of lherzolitic serpentine. On the flanks of the Micciano Hill the reddish, spheroidal diabase is overlain by Eocene violet schists and grey limestone, of which the latter exhibits traces of extinct *soffioni*, the surface all around being greatly altered and incrustated, like that of the active steam jets in the hills further south. Close to the serpentinous depression occurs a mass of euphotide in contact with a metalliferous band of steatitic rock traversed by veins of diabase. On the road down to the Trossa torrent the sedimentary strata are clearly seen between the two diabasic masses, very like the two similarly situated masses of Mte. Massi and Poggio alla Croce of the Montecatini group on the opposite side of the valley. On the same road nearer to Micciano, the contact of the reddish spheroidal diabase and the Eocene limestone is marked by intermediate diabasic and calcareous breccia. East and south of the principal Monterufoli serpentine group lie the smaller, similar masses of Montecerboli and Serrazzano, both in close proximity to the active *soffioni* which, aligned on fissures, extend about 12 km. further south to Castelnuovo

and Monterotondo and cover an area of no less than 100 sq. km.[1]

(3) *The Montecastelli Group.*—This area, south-east of Pomarance, between the Trossa torrent and the Upper Cecina, at about 500 m. altitude, is smaller than, and virtually an extension of, the preceding one. Like the latter, it is chiefly composed of serpentine which forms a cupoliform mass fringed on its southern margin by euphotide traversed by diabase veins and more or less overlain by Pliocene deposits. In the Pavona ravine at the foot of the interesting eminence of Rocca Sillana, composed of serpentine, superficially reddish euphotide appears in the serpentine as a vein which in its turn is encased in the lenticular, globular euphotide mass of Grotta Mugnaioli, the euphotide being as usual greatly decomposed and here reduced to a steatitic paste containing cupriferous nodules. Near Rocca Sillana the serpentine exhibits distinct traces of its lherzolitic origin by the presence of enstatite and of olivine granules which protrude from the reddened surface of the rock.[2] A short distance north of Montecastelli occur some small outliers of euphotide and diabase, while about 10 km. south lie several outcrops near and at Travale. The latter outcrop, called Mte. Gabbro, is situated near the Liassic group of Le Cornate (1059 m.), which with Poggio di Montieri (1051 m.) forms the highest point of that part of the metalliferous range. Mte. Gabbro constitutes a small cupola of lherzolitic serpentine with chalcedonic concretions, and is overlain in part by Eocene limestone and red diaspri. The Montecastelli group and its outliers form the last ophiolithic masses of the Cecina Basin.

IV. The Groups West, North, and South of Siena. (Figs. 2–4, p. 127.)

These groups all lie in the outer zone or belt of the metalliferous range, in a line roughly north to south, more or less in the region of the Hills of Siena, from which city the Val d'Elsa group is distant 15 km. to the west, the Montaione group 30 km. to the north, and the groups of Murlo and Montemassi lie 20 km. to the south.

1. *The Val d'Elsa Group* (Fig. 2), on the western margin of the Permian and Triassic range called the Montagnola Senese, lies at the foot of Mte. Vasone (402 m.) at about 300 m. altitude, its base being skirted by the high road and the river of Val d'Elsa. It is practically an extension of the Montecastelli group on the left of the Cecina Valley, from which in a distance of about 19 km. it is separated by the divide of the Cecina and Elsa watersheds. The principal mass, about 12 sq. km. in area, is mainly composed of euphotide with diabase, but in great part schistose and decomposed

[1] An interesting memoir on the volcanic phenomena of this region is that by G. d'Archiardi, "Origine dell' acido borico dei soffioni boriferi in Toscana": Atti Acc. Lincei, Roma, 1909, fasc. v.

[2] This rock has been microscopically examined by L. Busatti, "Sulla lherzolite di Rocca Sillana": Mem. Soc. Tosc. Sc. nat., 1889, fasc. x.

to argillaceous material. It lies in the Eocene horizon, which also includes the small outlying group of more or less decomposed and indistinctly defined serpentine and euphotide with diabasic veins near Rencina, on the northern margin of the Montagnola Senese.

2. *The Montaione Group* (Fig. 2), on a spur of 350 to 550 m. altitude between the Elsa and Era Valleys, consists of the ophiolithic cluster of Montaione, S. Vivaldo, and Montignoso, and forms, with the concomitant Eocene sedimentary strata, a belt round the Permo-Carboniferous outcrop of Jano [1] in the western part of that interesting district, covering about 50 sq. km. Montaione itself is built on spheroidal diabase with euphotide, which latter extends north to the cupriferous euphotide mass of S. Biagio. In this, at one time actively worked mine, the saussuritic and smaragditic euphotide is overlain by a mass of unaltered, labradoritic euphotide, the contact between the two masses being formed by a steatitic band in which the globular cupriferous ore is embedded. The gradual decomposition of the lower euphotide mass is well marked, from the porphyritic type with diallage crystals up to 10 centimetres in length to serpentinous schist and finally to the steatitic ore-bearing paste or *losima.*

Among the other ophiolithic outcrops are notably those of Gambassi, of serpentine, euphotide, and diabase, the euphotide with diabase veins being also metalliferous ; those of Rio dei Casciani, where the euphotide exhibits gradually increasing diabase veins until it is eclipsed by a mass of spheroidal diabase ; those of Montignoso, whose castle is built on an eminence of lherzolitic serpentine ; and lastly those of Palagio and S. Vivaldo, in the centre of the area, where a mass composed of steatite, asbestos, and semi-opaline, intensely green resinite is associated with serpentine and euphotide overlain by Pliocene deposits.

South-west of Montignoso towards Volterra occur the ophiolithic outcrops of Le Cetine, where a formerly important nodulous cupriferous deposit is embedded in steatitic euphotide and diabase, and the isolated mass of Monte Nero composed of serpentine and overlying diabase. Both these and the Montaione groups are zonally aligned with those of Montecatini on the right of the Cecina Valley, from which they are separated by the Pliocene depression of the Era Valley descending from Volterra.

3. *The Murlo Group* (Fig. 3), spread over an area of about 100 sq. km. at 550 m. altitude in the Eocene horizon between the Merse and Ombrone Valleys south of Siena, comprises about a dozen ophiolithic masses of lherzolitic serpentine, euphotide, and diabase in the usual order of superposition. Serpentine predominates in the western outcrops near Vallerona, euphotide, south-west on the right of the Merse in the masses of Santo, Pari, and Casenovale, as also north-east in those of Vescovado and the lignite district of Murlo, and spheroidal diabase north in the mass of Crevole, here overlain by

[1] *Vide* the preceding paper, "The Permian and Triassic Belt of the Tuscan Subapennines."

red diaspri. The mass of Mte. Pescini, close to the Merse, contains thin veins of calcopyrite in a steatitic paste between red variolitic diabase and serpentine.

4. *The Montemassi Group* (Fig. 4). Near Mte. Alto (797 m.) at the south-west end of the Permian range south of Siena, occur in the Eocene strata, close to the trachytic masses of Roccastrada, the ophiolithic outcrops of Montemassi and Roccatederighi. Here, too, the serpentine is overlain by euphotide and reddish spheroidal diabase, upon which rest Eocene green indurated ftaniti schists, red diaspri, and limestone. The scattered cupriferous deposits of this locality are as usual embedded in steatitic euphotide. Some other small masses of euphotide and diabase crop out about 10 km. north-west of Montemassi in the Eocene strata near Massa Marittima, and complete the series of ophiolithic groups of the metalliferous range on the mainland.

Conclusions.

The examination of the Eocene ophiolithic groups of the Apuan Alps and Tuscan Subapennines described in these pages and occupying in the aggregate over 900 sq. km. leads to the following general conclusions :—

1. The superposition of the three principal basic constituents of the different areas is, in normal conditions, invariably the same, that is, serpentine, euphodite, and diabase in upward succession ; in the rare absence of euphotide, diabase overlies serpentine direct. The serpentine masses frequently contain veins and intercalations of euphotide, less frequently of diabase, which, on the other hand, abound in euphotide. This order of superposition and intercalation corresponds to the order of eruption and consolidation from essentially the same magma, which also produced the occasionally associated granitic rocks as acid concentrations. The intimate association of diabase and euphotide independently of serpentine warrants the inference that, while serpentine, as altered peridotite and the most basic of the three rocks, represents a separate initial phase of eruption and of rapid cooling and consolidation, euphotide and porphyritic diabase consolidated and crystallized more slowly and, together with aphanitic diabase, represent a somewhat later stage of submarine eruptive activity.

2. The ophiolithic rocks overlie each other with great regularity and are lenticularly infolded in the Eocene sedimentary strata, which as a rule show no evidence of angular intrusion, apophyses, or contact metamorphism. The eruptive masses are, therefore, submarine lava-streams which, at relatively short intervals within the same geological period, flowed, expanded, and became infolded in the planes of the still plastic sedimentary formation.

3. The metalliferous, mainly cupriferous deposits occur in veins, more frequently in nodules and aggregations embedded almost invariably in decomposed steatitic euphotide, more rarely in

porphyritic diabase, and never in serpentine, though often at or near the contact of the ophiolithic rocks with each other or with the sedimentary strata.[1] The greater permeability of euphotide and porphyritic diabase (as compared with serpentine and aphanitic diabase) facilitated the submarine formation of metalliferous deposits in fissures and cavities of those rocks by hydration, oxidation, and the enormous pressure of water, while the mineral solutions, aided by thermal springs, at the same time decomposed the felspathic and ferro-magnesian material of those rocks to the characteristic steatitic paste in which the deposits are embedded.

4. The Eocene ophiolithic groups of the Apuan Alps and Tuscany, like those of Eastern Liguria, are the remnants, not of subaerial volcanoes or their craters or channels of eruption, of which there is no trace or evidence, but of extensive submarine lava-flows raised in situ[2] with the infolding sedimentary formation during repeated earth movements in Miocene times. After this uprise the originally much more extensive, for the greater part coastal ophiolithic areas were gradually separated into the present zonal groups by fluviatile and atmospheric denudation. These ophiolithic groups thus represent the earliest period of Tertiary submarine eruptive activity in Eastern Liguria and Tuscany, followed by the stupendous subaerial eruptions of volcanic lavas and tuffs along the southern Tyrrhenean coast in Post-Tertiary times.

[1] Experimental shafts in search of metalliferous deposits in the ophiolithic masses of Liguria and Tuscany are nearly always driven in euphotide, often through serpentine and diabase in order to reach a euphotide vein or a lenticular mass of that rock.

[2] The essentially lenticular character of the ophiolithic masses has been quoted by G. Steinmann ("Alpen und Apennin": Mon. Ber. D. Geol. Ges., 1907, p. 177) in support of their being, not in situ, but transported areas; this hypothesis is, however, negatived by their origin as submarine lava-flows, which also accounts for the absence of visible channels of eruption. These were probably fissures rather than volcanic shafts, which obviously shifted and became obliterated during the uprise of the submarine formations and later earth movements.

XIII.

The Volcanic (Trachytic) Groups of the Tuscan Subapennines.

THE Hills of the Maremma region of Tuscany, extending from the Tyrrhenean coast inland for about 50 km., constitute the inner, more strictly littoral, and predominantly Tertiary zone or belt of the Tuscan Subapennines. Besides the ophiolithic groups described in the preceding paper,[1] they include the remarkable and interesting volcanic, mainly trachytic groups of Monte Amiata, Roccastrada, and Campiglia Marittima, with the smaller outlying masses of Radicofani, Montecatini, Orciatico, and the granitic mass of Gavorrano. All these groups lie collectively in the Tuscan metalliferous range, and, aligned in a zone N.W. to S.E., more or less parallel to the more northern Eocene ophiolithic zone from Leghorn to the Cecina Valley and the Murlo Hills south of Siena, mark a stage of eruptive activity intermediate between that northern zone and the great Roman Quaternary volcanic region of the Bolsena, Viterbo, and Bracciano Hills which immediately adjoins the southern boundary of Tuscany at the River Fiora.

I. The Monte Amiata and Radicofani Groups. (F. 1, 3, pp. 137–9.)

1. *Monte Amiata.*

General Features.—This highly characteristic region is not confined only to the great volcanic mass which has for many years constituted its chief geological centre of attraction, but forms the central, largest, and highest part of a sedimentary massif midway between the Permian belt on the north and the volcanic Bolsena region on the south. Trending S.W. to N.E., this massif covers 20 and 10 km. in length and width, and along its axis includes as its highest points Mte. Labbro (1,187 m.), Mte. Amiata (1,734 m.), and Poggio Zoccolino (1,065 m.). Although the predominant sedimentary formation is the Eocene, all the three constituent groups exhibit in their upper parts some Liassic and Cretaceous outcrops, while several others fringe the massif on its southern margin.

Monte Amiata owes its commanding position at an altitude fully 600 m. above the surrounding hills of Southern Tuscany to its great trachytic cone [2] superposed on the sedimentary massif. The lowest contact of the two formations lies approximately at the 700 metres contour and can be distinctly followed along the northern base of the

[1] "The Ophiolithic Groups of the Tuscan Subapennines."

[2] The volcanic mass of Mte. Amiata rises from the base all round at a fairly uniform angle of about 9 degrees, culminating in La Crocina; its general form is thus conical rather than domal.

cone even from a distance, very strikingly for instance from Siena, about 50 km. north, whence the contact appears as a long straight line above which rises the volcanic mass. Equally striking is the contact all round the base of the volcanic cone, which is 50 km. in circumference and covers an area of about 125 sq. km. Here the contact is marked by a large number of perennial springs which rise between the trachyte and the substratum of impermeable argillaceous schists, and account for the rich vegetation and numerous villages all round the base. Of these villages the nearest to the Mte. Amiata railway station, which lies 500 m. below in the Orcia Valley at a distance of 10 km., is Castel del Piano at the north-western end of the trachytic area. From here the contact line is skirted by a road which, running all round the western, southern, and eastern margin, passes in succession Arcidosso, Bagnore, S. Fiora, Bagnolo, Seragiolo, Pian Castagnaio, and the well-known Abbadia S. Salvatore, whence the circuit is completed along the northern margin by Vivo, Poggiolungo, and Ferriera. From these localities, all of which afford interesting exposures, paths lead through chestnut and beech woods up to La Crocina, the summit of Mte. Amiata (1,734 m.), the most convenient and geologically interesting ascent and descent being from Castel del Piano (652 m.) up to La Crocina and down to Abbadia (829 m.) or vice versa. Among the salient trachytic points which with La Crocina lie in the axis of the massif are notably Poggio Pinzi, Trauzzolo, and Montagnola, in the south-western part of the area, varying from 1,200 to 1,600 m. in altitude.

The Trachytic Area (Fig. 3).—The configuration of the trachytic area—10 to 15 km. in superficial length and width—is marked by several characteristic features. Among these are notably the three northern tongues or apophyses of Vivo, Ferriera, and Castel del Piano, and the three minor, southern ones of S. Fiora, Seragiolo, and Pian Castagnaio ; again, the ravine called Val d'Inferno, which opens from the summit out to the south and, although obviously due to erosion, has been erroneously regarded as the remains of a crater ; and, lastly, the enormous masses of trachytic blocks and detritus which extend from the eastern flank near Abbadia for several kilometres down to and over the sedimentary formation, this comparatively recent rockfall being due to the undermining of the subjacent strata by underground accumulations of water. For the rest the trachytic area is largely an agglomeration of blocks, mounds, banks, and cliffs, in part worn by denudation, the formation of cliffs called " Ripe " being more especially in evidence on the south-western margin between Arcidosso, Bagnore, and S. Fiora, where trachyte is quarried for building purposes.

The Sedimentary Substratum.—Apart fron the Eocene outcrops all round the trachytic base at 600 to 800 m. altitude as previously mentioned, a complete sequence of the sedimentary horizon is revealed in the underground workings of the mercury mine on the eastern margin between Abbadia S. Salvatore (829 m.) and Ermeta, a

point at 1,000 m. altitude about midway between Abbadia and the summit. Here the trachyte rests in inconsiderable depth upon Upper Eocene albarese limestone and galestri schists, which are underlain by Middle Eocene macigno sandstone and Lower Eocene nummulitic limestone with varicoloured schists. These Eocene strata rest in their turn on Cretaceous (Senonian) limestone and schists which overlie the Upper Liassic calcareous, argillaceous, and diaspri series. This sedimentary sequence, first ascertained by Lotti [1] as immediately subjacent to the trachyte cone, has an important bearing, not only upon the structure of Mte. Amiata before the volcanic eruption, but also upon the nature and extent of the latter, as will appear in the sequel.

The Trachytic Rocks.—The trachytic masses, more especially where they occur as marginal banks and cliffs, frequently exhibit a roughly stratiform appearance, and only in the more unaltered exposures near the summit and in the eroded beds of streams, e.g. near Bagnore, show their original massive structure. The trachytic rocks themselves, locally and indiscriminately called *peperino*, have been the subject of many investigations, but an examination in situ and under the microscope, while it reveals innumerable passages and varieties, in the main confirms the classification laid down by Vom Rath, Williams, and Novarese, and also adopted by Lotti, into two main groups.[2] One of these, comprising the essentially marginal masses, is highly vitreous, granitoid, and finely granular, while the other, comprising the central and notably the western masses, is devitrified and microfelsitic with large phenocrysts. The first or vitreous rock, white to steel grey, and rough to the touch, is composed of a transparent groundmass subdivided into vitreous, spherical globules and containing small crystals of sanidine, plagioclase (labradorite), hypersthene, augite, bronzite, and biotite, with magnetite and pyrite. In some localities the rock is of blackish colour, due to innumerable black specks in the vitreous groundmass, which also contains vitro-

[1] B. Lotti, "Il Monte Amiata": Boll. R. Com. geol., 1878, pp. 251, 363; Geologia Toscana, 1910, p. 346.

[2] G. Vom Rath, "Radicofani und Monte Amiata": Zeitsch. D. Geol. Ges., Berlin, 1865. J. F. Williams, "Mte. Amiata": Neues Jahrbuch Miner., etc., 1887, and Boll. R. Com., 1887, p. 285. This is, both as regards micro- and chemical analyses, one of the most important contributions on Mte. Amiata. V. Novarese, "Varietà Trachitica, Mte. Amiata": ibid., 1888, p. 225. G. Sturli, "Analysis of Mte. Amiata Trachyte": Gazz. Chim. Ital., 1902; L. Ricciardi, ibid., 1888. E. Clerici, "Monte Amiata": Boll. Soc. geol. ital., 1903, p. cxxxvi. A. Verri, ibid., p. 9.

V. Sabatini, "Vulcani Cimini" (Mem. descr. R. Com. geol., 1912, p. 341), regards the Mte. Amiata trachytes as being probably tuff-peperino, and only the andesitic variety as effusive lava. This view, based on the analogy of his four gradations of tuff-peperino in the Cimini (Viterbo) region, is open to doubt, for in the volcanic mass of Mte. Amiata the evidence of scoriæ is insignificant and the surrounding area is totally devoid of explosively ejected material such as characterizes, and enormously predominates in, the Cimini and the other Roman volcanic regions. Moreover, all the trachytic rocks of Mte. Amiata exhibit fluidal structure.

The Volcanic Groups of the Tuscan Subapennines.

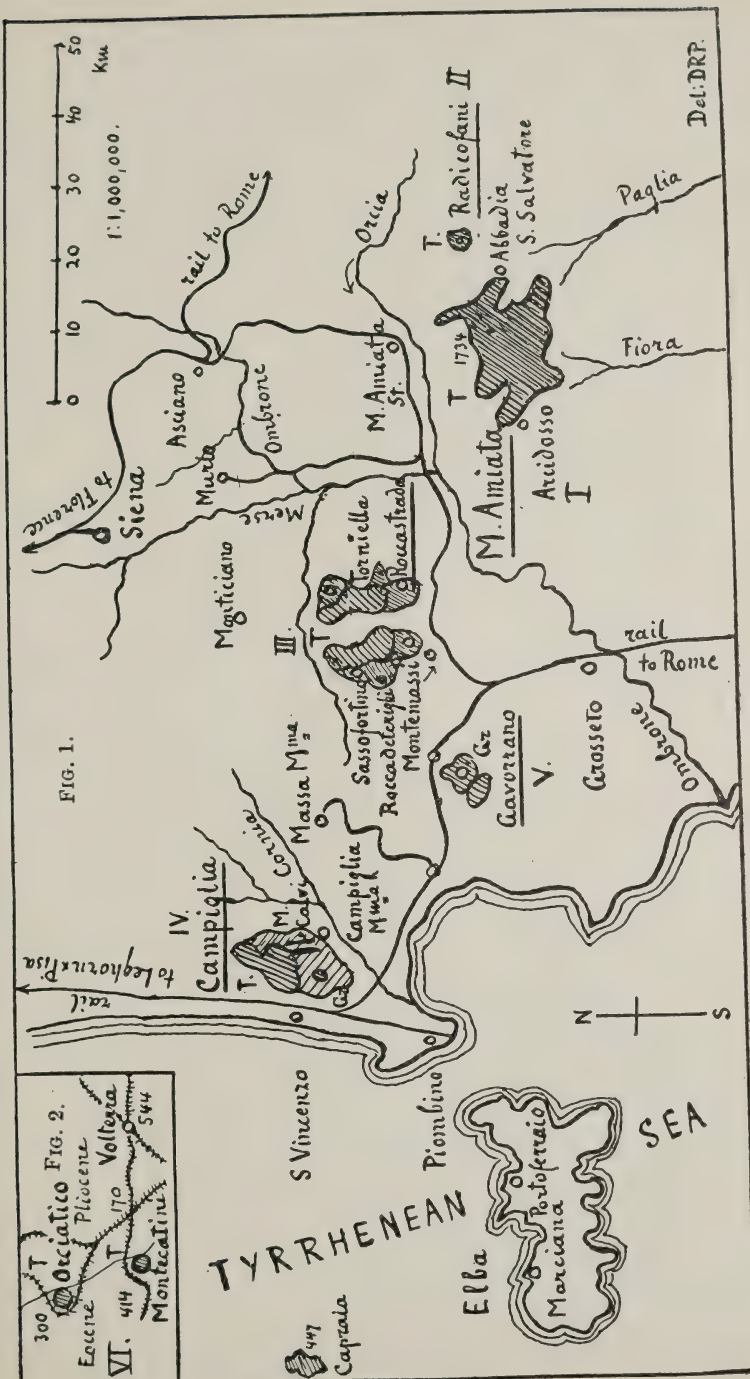


FIG. 1.

FIG. 2.

microfelsitic granules with fluidal structure and liquid inclusions. The rocks of the second or microfelsitic type of porphyritic structure, of whitish grey to pale yellow and reddish colour and more opaque aspect, contain large sanidine crystals up to 3 centimetres, biotite, and smaller crystals of plagioclase, hypersthene, and augite. Besides these leading types occurs a more basic subordinate andesitic-augitic variety of trachyte with predominant plagioclase. There is a general tendency to an increase of crystallinity, but, on the other hand, to a decrease of acidity from the marginal, vitreous, to the central, devitrified, microfelsitic rocks, the former containing from 65 to 67, the latter from 60 to 64, and subordinate andesitic, more basic variety 60 per cent of silica. Nowhere, however, is there a clear line of division between the two main types which constantly graduate into each other.

Of the marginal, vitreous, whitish-grey trachyte with small, both macro- and micro-phenocrysts, interesting typical exposures are those of Vivo in the north-eastern tongue, of Castel del Piano, and also in the banks between Arcidosso and Bagnore on the western margin. The black variety occurs at Pian Castagnaio on the south-eastern margin, and the steel-grey, reddish, incipiently altered variety near Abbadia. Again, the central, microfelsitic, porphyritic type with large phenocrysts is exposed on the summit of La Crocina, also on Poggio Pinzi, Montagnola, and Trauzzolo, while the andesitic variety occurs notably in Pian del Macinaio in the north-eastern part of the area.[1]

Inclusions.—A remarkable feature in both the leading types of trachyte are the cellular inclusions locally called *anime di sasso*, which appear non-adhesive, indeed isolated in the encasing rock. They consist of more or less rounded or globular, also angular fragments of porous trachytic, andesitic, and scoriaceous rock, of graphite, mica, also of sedimentary and metamorphic rock, as much as 70 centimetres in length or diameter ; in places where the encasing rock is disintegrated those fragements lie loosely on the ground.[2] Another local feature are the so-called pearls or tears (*lacrime*) of S. Fiora, which occur as inclusions in the cavities of trachyte, and consist of large globules of pure quartz whose nuclei are crystalline, while externally the quartz is amorphous. The phenomenon is, as Lotti has pointed out, probably due to the same process of silicification as the diatomaceous *farina fossile* or Kieselgur.

Among other interesting features of the Mte. Amiata group is the occurrence of cinnabar near Abbadia S. Salvatore in a chaotic mass of trachytic, Eocene, and Liassic sedimentary rocks—the rockfall already

[1] This variety was first recognized by A. Verri, "Monte Amiata" : Boll. Soc. geol. ital., 1903, pp. 10 and 361.

[2] Rosenbusch determined some *anime di sasso* inclusions as sedimentary fragments metamorphosed by the eruptive trachyte. C. De Stefani, "Roccie vulcaniche" : Boll. R. Com. geol., 1888, p. 221. E. Artini, Appunti petrogr. roccie italiane, Rendic. Ist. Lomb., 1893.

The Volcanic Groups of the Tuscan Subapennines.

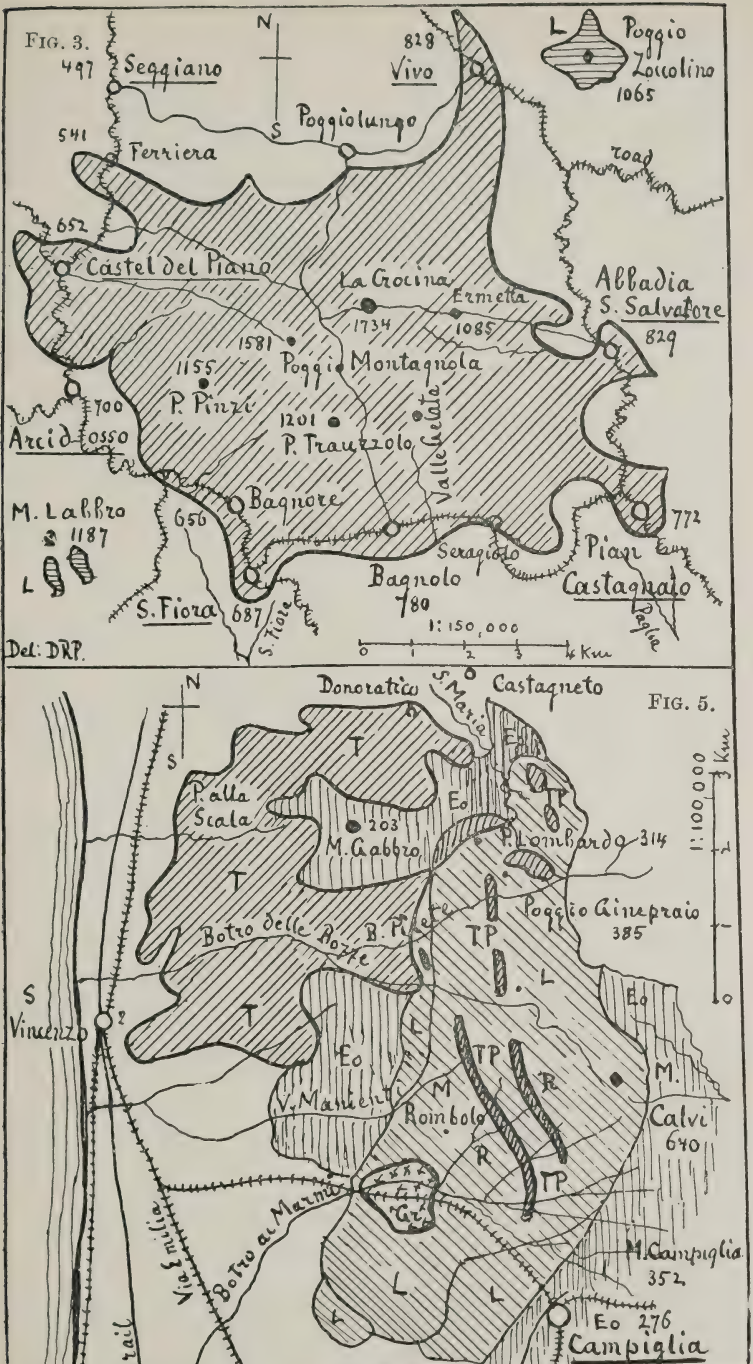


FIG. 3.—The Monte Amiata Group. FIG. 5.—The Campiglia Marittima Group. T = Trachyte; TP = Porphyritic Trachyte; Gr = Granite; R = Rhætian; L = Lias; Eo = Eocene.

mentioned—notably in an Eocene fissure filled with a cinnabar-bearing argillaceous mass in contact with overlying trachyte. These deposits, now worked for mercury, are due to subterranean mineral springs which circulate in the sedimentary strata and are acted upon by carbonate of lime abstracted from the overlying porous trachyte, whereby the cinnabar is precipitated and deposited as incrustations.[1]

Another and direct trachytic product is the *farina fossile*, i.e. the diatomaceous siliceous earth or Kieselgur which is found at the base of the trachytic masses in various localities, e.g. near S. Fiora and Bagnolo on the southern, and notably near Arcidosso and Castel del Piano on the western, margin. Here the trachyte is generally overlain by argillaceous clay and sand, i.e. disintegrated trachytic material in which the *farina fossile* forms a variable stratum. The clear, fine, flaky, and extremely light earth is composed almost exclusively, viz. up to 85 per cent, of diatomaceous silica, and is now used in the manufacture of dynamite.[2]

Closely related to the *farina fossile* are the yellow and dark chestnut-coloured earths called *terra gialla* and *terra d'ombra* or *bolo*, obtained by the action of ferruginous water upon trachyte and collected in trachyte tanks, the dissolved iron being precipitated and the argillaceous material held in solution and then dried. This chemical process takes place more especially in the depressions at the base of the trachytic masses where the ferruginous water collects and emerges. Ferruginous springs, however, occur also in the higher parts, i.e. in the gullies of the trachytic cone up to 900 m. altitude, with the same decomposing effect.

Origin and Age of the Trachytic Masses.—The two leading types of the Mte. Amiata trachyte and their varieties, while differing in petrological structure and in the percentage of silica, are substantially of the same lithological composition, constituting a single type of hypersthenic-biotitic trachyte. The predominance of the microfelsitic, devitrified, porphyritic type in the central part of the trachytic area led Williams to regard it as the more slowly consolidated nucleus round which the marginal mass, cooling and consolidating more rapidly, assumed a vitreous, liparitic character.[3] On the other hand, the porphyritic trachyte is found to overlie the marginal type on Poggio Pinzi (1,155 m.) in the western part of the area, and in a quarry near Arcidosso appears as a lenticular mass in that marginal type. As a rule, the central type forms the upper masses, the marginal appears more in the depressions and in the eroded beds

[1] Cinnabar deposits occur also at various points in the Eocene sedimentary strata on the southern flanks of Mte. Amiata, where, e.g. in the Siele ravine, they were already worked by the Etruscans, who used it to colour their terra-cotta vases.

[2] The most important researches in diatomaceous deposits are by E. Clerici (Boll. Soc. geol. ital., 1903, Mte. Amiata), not only in reference to *farina fossile*, but also in relation to the distinction between marine and lacustrine deposits in the volcanic regions around Rome.

[3] T. F. Williams, op. cit.

of streams and torrents throughout the area. This fact warrants the inference that the marginal, rather than the central type constitutes the primary effusion and the predominant trachyte. In any case there is reason to assume that the entire volcanic mass of Mte. Amiata represents one period of eruption of successive lava-flows rather than several periods of volcanic activity.[1] In the absence of a well-defined crater, as also of any appreciable quantity of scoriæ in any part of the mass, the existence of a fissure in the sedimentary substratum S.W. to N.E., i.e. in the direction of the axis of the massif, affords the best solution of the problem, the direction of the fissure being, moreover, indicated by several thermal springs and sulphurous emanations concordantly aligned. Accordingly, the eruption was not of a violent explosive, but of an effusive character, i.e. the magma welled up through the fissure and overflowed the sedimentary strata on both sides, some of the lava streams forming the tongues or apophyses, others the marginal banks and cliffs already mentioned.

The age of the trachytic mass of Mte. Amiata admits of little diversity of opinion. The fact that nowhere in the Pliocene deposits which surround the massif have any trachytic pebbles, blocks, or fragments been found, clearly proves the eruptive masses to be of Post-Pliocene age.[2] The eruption must therefore have taken place when the massif was still surrounded by, but had begun to emerge from, the slowly receding sea. Thus the trachytic cupola was formed in early Quaternary times, and subaerially, not as a so-called crater- or strato-volcano, but by slowly overflowing and expanding lava streams, i.e. more as a homogeneous cone.

As previously stated, the sedimentary Liassic and Eocene beds below the trachyte near Abbadia S. Salvatore reach up to an altitude of 1,000 m., that is 300 m. above the base of the trachytic cone round its periphery. In other parts, too, notably in some eroded stream-beds, Eocene strata are disclosed below the trachyte at about the same altitude. The opinion formerly held that the difference of level between the base (700 m.) and the summit of the trachytic masses (1,734 m.) represents a thickness throughout the cone of at least 1,000 m. may therefore be discarded as obviously exaggerated. In the Abbadia mine the trachyte overlying the Eocene strata only

[1] Sabatini (op. cit., p. 348) regards the variations of silica percentage (60 to 67 p.c.) in the Mte. Amiata rocks as proof of at least four distinct eruptions of decreasing magmatic acidity. But the trachytic varieties at many points graduate into and overlie each other without intermediate scoriæ or extraneous deposits; it is therefore probable that they are collectively the product of the same magma of varying acidity and that the eruptions, i.e. a succession of lava-flows, took place at relatively short intervals within one period of volcanic activity. This is borne out by the phenomena of Mount Pelée where the acidity of the magma varied from 60 to 63 p.c. during the eruptive period of 1902.

[2] This is confirmed by a Pliocene marine deposit which Lotti found below the trachyte near Pian Castagnaio in the south-east corner of volcanic cone. It contains no trace of trachytic detritus. Op. cit., p. 350.

reaches about 150 m. in thickness, and as the sedimentary strata are not horizontal, but incline at an upward angle, they indicate the probably dome-shaped form of the sedimentary massif or substratum. The overlying trachytic mass therefore probably does not exceed 100 to 150 m. in thickness even at the summit, and this affords additional proof that Mte. Amiata is not a crater-volcano, but that its volcanic mass is simply a sheet or mantle due to lava-flows welling up from a fissure in the sedimentary massif.[1] The latter thus presented, before the eruption, outlines very similar to those of its neighbours on either side, Mte. Labbro and Mte. Zoccolino, with which it forms a zonally aligned group. The greater elevation of Mte. Amiata is probably due to a greater Post-Pliocene compression and uprise at the central part of the whole group, which latter originally formed one continuous dome-shaped massif.

2. *Radicofani.* (Fig. 1, p. 137.)

Closely related to, and aligned with the trachytic mass of Mte. Amiata, about 10 km. east of the latter, lies the small but highly interesting volcanic mass of Radicofani, which, at an altitude of 896 m., forms an isolated cone in the large Pliocene area midway between Mte. Amiata and Mte. Cetona (1,148 m.). The volcanic mass, rising about 500 m. above the rivers Orcia and Paglia, which traverse the Pliocene marl area on the north and south respectively, is composed of basaltic rocks in three varieties : the lowest, forming the south-eastern, oldest part and nucleus, is doleritic, highly peridotitic, dark grey and black ; the upper and predominant rock is more andesitic with much olivine, of pale and dark grey colour ; the third variety is again doleritic, but of reddish-brown colour. All three varieties are of compact and microcrystalline structure with orthoclase (sanidine) and plagioclase microcrysts and segregations of olivine, augite, and magnetite. The felspar of the doleritic variety is in part vitreous with magnetite specks, while the reddish colour is due to the olivine being altered to a bright-red mineral diffused throughout the groundmass. The doleritic rock shows vertical columnar and prismatic structure and contains 54 per cent of silica, the rather more acid, andesitic rock 55 per cent.[2] The difference between the three basaltic rocks is, therefore, not one of composition, but mainly of aspect, colour, and structure. Associated with the upper or andesitic rock is an earthy, disintegrated andesite which contains geodes with amorphous, colourless, and also pale amethyst-

[1] The volcanic mass of Mte. Amiata represents, at 130 sq. km. and 100 m. thickness, 13 cubic km., viz. only one-seventh of the Cimini volcanoes, composed, according to Sabatini's view, almost entirely of tuffs with only a fractional proportion of lava.

[2] Micro- and chemical analyses of the Radicofani rocks are those by Vom Rath, op. cit., 1865, p. 405 ; L. Bucca, Boll. R. Com. geol., 1887, p. 274 ; G. Mercalli, Atti Soc. ital. Sc. nat., 1887, p. 87 ; L. Ricciardi, Gazz. Chimica ital., 1888.

coloured quartz, and passes to a greyish and reddish scoriaceous lava ; the latter with its detritus is in evidence more especially on the western and northern side of the summit crowned by the ruins of an historic medieval castle in whose vaults the lava is exposed.

A noteworthy and much-discussed phenomenon of the volcanic area of Radicofani are the numerous blocks of volcanic rock, some of them as large as 10 cubic metres, which are scattered over the surrounding, somewhat lower Pliocene hills even beyond the intervening watercourses within a radius up to 6 kilometres, some of these blocks having been found even at the Eocene base of Mte. Amiata. The phenomenon has been variously attributed to a formerly much greater extension of the volcanic area by radial lava streams, of which these blocks are assumed to be remains ; to a violent last phase of explosive eruption caused by the displacement of the eruptive axis or fissure of Mte. Amiata after the latter volcano had become inactive ; or, again, to the more recent process of torrential denudation of the Pliocene beds, in the course of which the blocks, detached from the volcanic cone by landslips and rockfalls, were carried to their present location before the Pliocene area was cut up by intervening watercourses, as it is now. The last of these interpretations commends itself as the most natural and adequate, the more so as, except these erratic blocks, no trace of bombs, ashes, or other volcanic material has been found in the surrounding Pliocene area. The cone has evidently been, and is even now, slowly crumbling away, a process largely due to the copious springs which, issuing at its base, loosen and remove the supporting Pliocene, mainly argillaceous beds.[1]

The doleritic and andesitic rocks of Radicofani are about 10 per cent more basic than the trachytes of Mte. Amiata. They bear close analogy to some of the basaltic rocks of the volcanic regions north of Rome, in part also to some of the olivine andesites of the island of Capraja [2] (Tuscan archipelago), which contains the equivalents of both the trachytic Mte. Amiata and the andesitic Radicofani rocks. The subaerial eruption of Radicofani took place in Early Quaternary times, like that of Mte. Amiata, but somewhat later than the latter, probably as a secondary and final effusive phase of volcanic activity along the fissure on which both groups are aligned. The cone, being built up of several types of basaltic rock about 200 m. in thickness, was probably formed, like Mte. Amiata, by several successive effusive lava streams, but without violent explosions, as is shown by the total absence of ejected bombs or ashes either in situ or in the surrounding area. The cone is therefore, like Mte. Amiata, of the homogeneous rather than the strato-volcanic type, both cones being, moreover,

[1] The whole Pliocene area around and north of Radicofani is greatly cut up and liable to landslips ; the marly region is known as " the crags of Siena ".

[2] L. Bucca, Boll. R. Com. geol., 1887. E. Mattirolo, cit. in Lotti, op. cit., p. 352.

without concentric rims and without visible craters.[1] Moderni is disposed to regard it as an eccentric volcano of the Bolsena group [2]; but the latter, apart from its probably more recent Quaternary age, lies south-west at a distance of over 20 km., whereas Mte. Amiata lies immediately west at less than half that distance. The Radicofani cone can therefore only be regarded as an outlier and a secondary eruptive phase of Mte. Amiata as the nearer group with which it is zonally aligned.

II. The Roccastrada and Sassofortino Groups. (Figs. 1, p. 137; 4, p. 145.)

About 30 km. north-west from Mte. Amiata and midway between the latter and the Campiglia Marittima group on the coast lies the cluster of trachytic masses of Roccastrada, Orsa, Grottoni, Torniella, and that of Sassofortino near Mte. Sassoforte, Roccatederighi, and Caminino at altitudes from 300 to 800 m. The first four of these masses crop out in the Permian, Rhætian, and Pliocene immediately east of the Permian hill Mte. Alto (797 m.),[3] the other three in the Permian, Eocene, Miocene, and Pliocene strata immediately west of that hill. The Permian, mainly schists and verrucano, thus forms the substratum on and round which are deposited the more recent formations with the volcanic masses superposed. Both Roccastrada and Roccadeterighi, as also Torniella, Sassofortino, and Caminino, are built on the trachytic masses bearing those names; Mte. Sassoforte, the highest trachytic point (787 m.), is crowned by the ruins of a castle which is built of large blocks of trachyte naturally cemented by disintegrated trachytic material. The Caminino mass, on the south-west, slopes down to the alluvial plain which extends to Grosseto and the coast. The whole hilly region is, around its margin on the west, north, and east, deeply eroded by the Asina, Farma, and Gretano torrents, which, by their tributaries radiating from the centre, collect the copious drainage of the Permian, ophiolithic, trachytic, and Tertiary sedimentary formations and discharge into the Rivers Bruno and Ombrone. The trachytic outcrops superposed on the sedimentary strata do not represent so many separate centres of eruption, but are the result of fluviatile and atmospheric denudation which has broken up the original area into separate masses and deposited on the lower sedimentary heights around their bases, and even in the alluvial plain, considerable trachytic blocks and detritus.[4] The seven outcrops forming the two originally dome-

[1] The distinction between homogeneous, i.e. effusive, and stratified, i.e. extrusive, volcanoes is extremely elastic, the stratified type being often both extrusive and effusive, i.e. composite.

[2] P. Moderni, "Vulcani Vulsini (Bolsena)": Boll. R. Com. geol., 1904, p. 198.

[3] Mte. Alto forms part of the Monticione and Roccastrada Permian massif described in a previous paper.

[4] See p. 145, note 1.

shaped groups are thus the remnants of an extensive volcanic area of nearly 100 sq. km. which flanks the Permian of Mte. Alto on either side and in the aggregate almost equals that of Mte. Amiata. As in the latter and the Radicofani cones, so also in those of the Roccastrada region there is no reliable evidence of craters, and the

The Volcanic Groups of the Tuscan Subapennines.

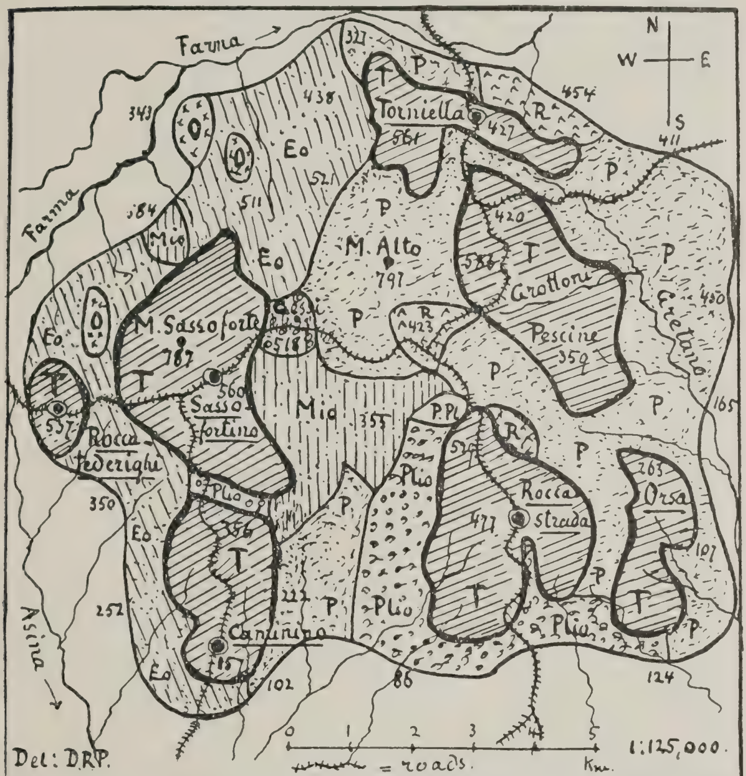


FIG. 4.—The Roccastrada and Sassofortino Groups. T = Trachyte; O = Ophiolithic Groups; P = Permian; R = Rhætian; Eo = Eocene; Mio = Miocene; Plio = Pliocene; P.Pl = Post-Pliocene Travertino.

eruptions must therefore have taken place as effusive, subaerial lava-flows descending north to south along two parallel fissures probably due to faults, the western coinciding with the Sassoforte and

[1] Some of these blocks are of enormous size, in one case, east of Mte. Alto, nearly 300 cubic metres. Such masses can only be due to rockfalls, as in the similar cases, though on a smaller scale, near Radicofani.

Caminino Hills, and the eastern with those of Torniella, Grottoni, and Roccastrada. Contiguous to the former lie the similarly aligned ophiolithic masses of Roccatederighi and Montemassi,[1] which proves this region to have been a centre of eruptive activity both in Eocene and Post-Pliocene times, the former eruption having been submarine, the latter subaerial.

The trachytic masses exhibit occasionally prismatic, columnar structure, and, in the upper parts, pseudo-stratification, e.g. near Roccastrada, Sassofortino, and Roccadeterighi, which last-named mass consists on the surface largely of huge piles of blocks. The trachyte, generally of pale-grey colour and traversed by numerous veins of a darker variety, is on the surface often cellular, friable, kaolinized, and earthy, but below compact and hard, suitable for building purposes. The various masses exhibit many subordinate passages and varieties, which, however, resolve themselves into three principal types similar to those of Mte. Amiata and Radicofani: (1) a vivid steel-grey, compact, finely granular, more or less vitreous rock; (2) a reddish-brown, fairly compact, more largely granular, cryptocrystalline variety; and (3) a reddish, cellular and compact, porphyritic rock with large phenocrysts. The three types are composed of a partly colourless, vitreous, partly microcrystalline, pellucid, occasionally nebulous groundmass with disseminated microcrystals or larger, porphyritic phenocrysts of sanidine, plagioclase, quartz both as small and large inclusions, abundant biotite and cordierite, and, as accessory micro-phenocrysts, hypersthene, apatite, magnetite, pyrite, and limonite. In the Torniella and Roccatederighi masses the porphyritic trachyte exhibits, besides the minerals named, orthoclase with vitreous inclusions in such numerous, large, and predominant phenocrysts as to resemble a quartz-orthoclase porphyry of entirely holocrystalline structure without any apparent groundmass. The normal trachyte of Mte. Sassoforte contains 71 per cent, that of the Torniella or eastern group 73 per cent silica [2]; it is therefore essentially a quartz-trachyte and considerably more acid than the quartzless trachyte of Mte. Amiata with 60 to 67 per cent, or the basaltic rock of Radicofani with 55 per cent silica. The sedimentary strata in contact with the trachytic masses show some evidence of metamorphism,[3] and as the latter overlie the Permian, Eocene, Miocene, and even Pliocene formations, their eruption must have taken place, like that of Mte. Amiata and Radicofani, in Early Quaternary times.

[1] "The Ophiolithic Groups of the Tuscan Subapennines."

[2] R. V. Matteucci, Boll. R. Com. geol., 1890, p. 237, and Boll. Soc. geol., 1891, p. 677, with map. In the trachytic masses between Roccastrada and Torniella, Matteucci found *farina fossile* of 80 per cent silica, and in other parts *anime di sasso* inclusions.

[3] Lotti mentions a case of Pliocene fossiliferous marl being transformed to porcellanite at the contact with trachyte near Gessi, between Roccastrada and Sassofortino, op. cit., p. 346, as additional proof of the Post-Pliocene age of the volcanic rock.

III. The Campiglia, Marittima, Gavorrano, and Val di Cecina Groups.

1. *Campiglia Marittima.* (Figs. 1, p. 137; 5, p. 139.)

General Features.—This group, one of the most interesting and complex of its kind in Tuscany, lies on the Tyrrhenean littoral, 30 km. west of the Roccastrada group, and midway between Leghorn and Grosseto. Its sedimentary and eruptive rocks, together with its metalliferous deposits, have for many years attracted the attention of geologists, not only on account of their intrinsic and local interest, but because of their geological connexion and analogy with those of the island of Elba situated about 35 km. south-west. The extreme points of the hilly, well-wooded group which is separated from the Eocene promontory of Piombino by Quaternary and alluvial deposits, and covers an area of 10 by 5 km. in length and width, are S. Vincenzo on the coast, Campiglia Marittima (276 m.) and Mte. Campiglia (349 m.) on the south, Mte. Calvi, the highest point (640 m.) on the east, and Donoratico and Castagneto on the north. The hills rise gradually from the coast to 200 and 300 m. altitude, including Mte. Gabbro, Rocca Silvestro, and Mte. Rombolo, and thence to the Campiglia and Mte. Calvi ridge which forms the divide between the group and the Cornia Valley on the east. On the western or littoral side the hills are intersected by several torrents which discharge direct into the sea, the principal being Botro ai Marmi, which rises near Campiglia and through whose rugged and geologically important glen runs the road from that place to the coastal Via Emilia and S. Vincenzo.

The Sedimentary Formations.—The lowest member of this series is, at the south end, an outcrop of Rhætian, crystalline, dark-grey, veined limestone or bardiglio at the base of the Liassic masses of Mte. Rombolo and Mte. Calvi, which extend to the smaller eastern group of Sassetta, separated from the former by a narrow belt of Eocene strata. The Lower Lias is represented more especially by the limestone mass of Mte. Calvi, which in the neighbouring Mte. Rombolo passes gradually to crystalline, saccharoidal, and fine statuary marble of ancient fame. This Lower Lias is fringed by red, pink, and pale-grey Middle Trias limestone, which at the northern end on Mte. S. Lucia near Castagneto forms a remarkably fine breccia or broccatello. The Upper Liassic rocks which overlie the Lower Lias on Mte. Calvi consist mainly of argillaceous limestone, yellow and red diaspri, and red schists kaolinized by disseminated pyrite and iron oxide. The Cretaceous (Senonian) is represented only by a narrow band of violet calcareous and argillaceous schists on the south-eastern margin of Mte. Calvi. The Eocene strata are composed chiefly of argillaceous limestone and schists, while macigno sandstone only occurs here and there in contact with the Mesozoic beds. The Eocene rocks appear in the northern part of the group as the outcrop of Mte. Gabbro surrounded by eruptive rocks, but are more largely

developed in the southern and eastern part, in which latter they rest direct against the Liassic beds of Mte. Calvi. All the sedimentary beds are more or less fossiliferous, except, of course, the highly crystalline, saccharoidal limestone metamorphosed by the adjacent eruptive rocks.

The Eruptive Area (Fig. 5).—The eruptive, mainly trachytic rocks occupy the whole north-western part from S. Vincenzo to Donoratico and Castagneto, and, together with some Eocene deposits, constitute fully half the total area of the Campiglia group. Besides these principal masses they appear as veins of considerable length in the Liassic formation of Mte. Calvi and Mte. Rombolo not far from a granitic outcrop in the Botro ai Marmi glen ; also as dykes in the north-eastern corner of the Middle and Upper Trias between Poggio Ginepraio and Poggio Lombardo at about 300 m. altitude, as well as in the deeply cut ravine of S. Maria.

The trachytic rocks are all quartziferous and present three principal types, two respectively with a vitreous and a microfelsitic groundmass, and the third of porphyritic structure. The first two constitute the irregular cupoliform anticline of the lower and upper hills from S. Vincenzo to Donoratico near Castagneto, rising from the sea to 100 and 200 m. altitude in a distance of about 8 km. The vitreous, grey and finely granular, essentially massive trachyte here forms with the Eocene island of Mte. Gabbro the predominant and upper part of the volcanic complex, while the microfelsitic, roughly stratiform, more coarsely granular and brick-red variety constitutes the subjacent masses. The exposures of the latter are restricted to the deeply eroded gullies, such as those of delle Rozze, Pilete, and Acqua Calda, and to some outcrops on the hills where the vitreous superficial trachyte has been removed by denudation. It is a noteworthy feature that the subjacent, more stratiform, and tabular trachyte closely conforms to the flexures of the upper, vitreous masses and also of the adjacent Eocene strata.

The third or porphyritic variety only appears in the Liassic formation, as already mentioned. It is strikingly conspicuous in two remarkable, parallel, more or less continuous bands or veins about 1 km. apart and up to 5 metres in thickness, which run from the south-eastern extremity of the group near Campiglia Marittima in the direction south-east to north-west at about 300 m. altitude, and are encased and intrusive in the white Lower Liassic limestone between Mte. Rombolo, Rocca Silvestro, and Mte. Calvi. The western vein is intermittently exposed for about 5 km., the eastern for about 2 km. in length, and after a break of 1 km. where vegetation and plantation impede observation, they reappear further north in the same direction, the eastern band again in the Lower Lias near Romitorio della Rocchetta, the western in the Upper Liassic schists. After another break the eastern vein expands further north to a larger dyke over 100 m. in thickness between Poggio Ginepraio and Poggio Lombardo, followed by another dyke still further north in the Upper

Liassic schists of the S. Maria glen. In these northern outcrops the porphyritic trachyte appears in close proximity to the vitreous and microfelsitic varieties near the contact line of the Liassic and Eocene strata.

The small granite mass already mentioned, occupying about 500 sq. m., crops out at 80 m. altitude in the lowest part of the sedimentary series, viz. in the Rhætian dark-grey crystalline limestone or bardiglio of the deeply eroded glen of Botro ai Marmi on the road about midway between Campiglia and the coastal Via Emilia. Except the transformation of the Rhætian compact limestone to crystalline, the sedimentary rocks in contact with the eruptive granite exhibit no evidence of alteration.

The Eruptive Rocks.—The predominant, *vitreous*, finely granular, grey, and massive trachyte is composed of a colourless, slightly brown glassy groundmass, in which are disseminated phenocrysts of sanidine, plagioclase, quartz, biotite, violet cordierite, often also augite, accessory scapolite, apatite, and zircone. The quartz, cordierite, and sanidine crystals contain vitreous, but exhibit no liquid inclusions. In some places, e.g. in the Botro delle Rozze glen and near the contact with the Eocene strata, the trachyte is pumaceous and only partially vitrified; in others it includes unaltered sedimentary fragments; again, in others it is transformed to yellow or red retinite, which latter also appears as breccia.

The *microfelsitic*, coarsely granular, brick-red, and pseudo-stratiform trachyte exhibits a colourless, fibrous, and scaly, also microcrystalline groundmass with disseminated phenocrysts of quartz, sanidine, plagioclase, and biotite, also accessory apatite, zircone, and magnetite. The quartz exhibits frequent vitreous, but no liquid inclusions. This variety contains neither scapolite, augite, nor cordierite, except the latter in the altered form of pinite. These characteristics equally apply to a dark-grey, occasionally white, banded, and less stratiform type, which occasionally forms a transition from the pale-grey, vitreous to the brick-red, microfelsitic trachyte. It occurs in banks and is quarried on account of its compactness. The difference of aspect and colour between the two principal varieties, grey and red, is very striking, more especially in the outcrops from S. Vincenzo to Donoratico and Castagneto. The microfelsitic type in places assumes a porphyritic structure with large phenocrysts of sanidine, and then resembles the typically porphyritic variety. A specially interesting exposure of the lower, stratiform trachyte is that near Poggio alla Scala at the north-western end of the group above the coastal Via Emilia where that rock forms a series of bands below the upper, vitreous type.

The *porphyritic*, white, yellowish to brownish trachyte is composed of a microcrystalline base of transparent sanidine, opaque orthoclase, oligoclase, quartz, and scales of biotite largely converted to chlorite, with segregations of iron oxide, also decomposed cordierite, and accessory apatite, zircone, and tourmaline; the rock exhibits

numerous vitreous and also liquid inclusions. The porphyritic phenocrysts are large elements of sanidine, orthoclase, and biotite. This porphyritic quartz-trachyte bears a striking resemblance to the Torniella variety of the Roccastrada group.

The *granite* of the Botro ai Marmi glen is of essentially though irregular granular structure. Its principal constituents are fine- to medium-grained, both monoclinic and triclinic felspar, quartz, and mica, with porphyritic segregations of larger felspar phenocrysts, clusters of black tourmaline, and accessory apatite and titanite. The quartz abounds in gaseous and liquid inclusions, and also exhibits micro-inclusions of biotite, apatite, zircone, and tourmaline. The phenocrysts of mica vary greatly in quantity and generally show chloritic alteration. The granite outcrop is traversed by more or less vertical veins of scapolite, both fibrous and in crystals more or less altered to meionite, and also contains, associated with felspar, segregations of cellular limonite derived from disseminated pyrite crystals. Associated with this eminently granular granite is a more microcrystalline variety with porphyritic phenocrysts of felspar, quartz, and a green chloritic substance derived from decomposed mica. This variety is, however, subordinate. The granite dyke is evidently part of deep-seated masses below the trachytes and consolidated more slowly than the latter under great superincumbent pressure.

The normal, predominant, vitreous quartz-trachyte of the Campiglia Marittima group contains 70·64, the porphyritic 70·92 per cent of silica,[1] the latter being therefore only slightly more acid than the former. Both types are thus in acidity very similar to the Roccastrada quartz-trachytes containing 71 to 73 per cent, but, like the latter, considerably more acid than the quartzless trachytic and basaltic rocks of Mte. Amiata and Radicofani respectively, with 60 to 65 and 54 to 55 per cent silica.

The Metalliferous Deposits.—Intimately associated with the eruptive rocks of the Campiglia Marittima group are the interesting, though now much reduced, metalliferous deposits which were already worked by the Etruscans, as is attested by the troughs, pits, and detritis of the ancient mines, mainly in and near the Botro ai Marmi glen previously mentioned. The deposits consist largely of pyrites, hematite, and limonite, and occur mainly in that glen associated with the granite dyke and the Liassic bardiglio beds of Mte. Rombolo and Mte. Calvi, in Mte. Valeria, Campo alle Bosche, and on Poggio

[1] Anal. Dalmer and Vom Rath.—Valuable contributions on the Campiglia region are those by : G. Vom Rath, "Fragmente aus Italien" : Zeitsch. D. G. Ges., 1866 ; A. d'Achiardi, "Trachite e porfido" and "Cordierite nel granito, etc." : Mem. Soc. tosc. Sc. nat., 1884 and 1875 ; K. Dalmer, "Quartz-trachyte von Campiglia" : N. Jahrb. Min. Geol., etc., 1887 ; B. Lotti, "Roccie eruttive felsp. di Campiglia Marittima" : Boll. R. Com. geol., 1887, with map, and op. cit., Toscana, 1910, p. 295. The intrusive vein-trachyte of Campiglia has been variously labelled as quartz porphyry (Vom Rath) and trachytoid quartz porphyry (d'Achiardi) ; but Dalmer's determination as porphyritic trachyte is the most adequate.

Acquaviva on the south side of the valley. They form essentially concretionary veins in the sedimentary and eruptive rocks, their close relationship to the latter being attested by the association of accessory copper, lead, zinc, and ferro-calciferous silicates with augite, ilvaite, epidote, and garnet, in close analogy with similar deposits of Elba.

It is a noteworthy feature that the porphyritic trachyte in proximity to the pyroxenic-ferriferous deposits passes to a pale augitic, microcrystalline porphyry of comparatively low acidity (60 per cent silica) ; it is composed of a pale-greenish groundmass with phenocrysts of sanidine, oligoclase, biotite, more or less altered olivine, and accessory magnetite and pyrite.[1] The veins of porphyritic trachyte are also partially mineralized, and even the Eocene strata near the deposits contain mineral traces and impregnations.

Age of the Eruptive Rocks.—The presence of Eocene fragments in the trachyte, and the assumed close relation of the latter to the granite dyke of Botro ai Marmi led Lotti to assign all the eruptive rocks of the Campiglia group to the Early or Middle Miocene. This age can, however, be legitimately claimed only for the deep-seated laccolitic granite closely analogous to the more southern granitic mass of Gavorrano and the great Post-Eocene granite masses of Elba. The trachytic masses, on the other hand, including the intrusive porphyritic veins and dykes,[2] bear so close an analogy to those of Mte. Amiata and Roccastrada, and are so closely related to the latter as also to those of the island of Capraja, that there is every reason to regard them as contemporaneous with those other Tuscan groups, that is, as Post-Pliocene. The absence of a crater, and the domal anticline of the trachytic masses, show that in this group too the eruptive phenomena were not of a violent, explosive or extrusive, but of a slowly effusive character by successive subaerial lava streams overflowing from a fissure in the subjacent sedimentary Eocene,[3] and expanding over the latter in their descent towards the sea.

[1] This augite-porphyry of the Ortaccio glen was first described by Vom Rath, op. cit., 1866, as a dyke quite different from the other trachytic rocks of Campiglia. It is, however, simply a basic modification of the porphyritic trachyte altered by the adjacent pyroxenic-ferriferous deposits when in solution.

[2] Between the intrusive porphyritic trachyte and the granite of Campiglia there is not improbably a genetic correlation, as there is between the quartz-porphyry and the granite of Elba ; but the porphyritic rock of Campiglia is vitreous and trachytic, and therefore a more recent eruptive emanation than the granite, whereas the Elban porphyry, of submarine origin, erupted immediately after the granite in the same Tertiary, Post-Eocene period.

[3] The Pliocene marine deposits along the coast are submerged and covered by alluvial deposits which contain abundant pebbles derived from the previously erupted trachytic masses. A thin Quaternary calcareous marine deposit, the *panchina* of the Tuscan coast and Elba, overlying the Eocene about 100 m. above S. Vincenzo on the Pianola road, marks the early Post-Pliocene rise of the littoral ; the trachytic masses which reach up to 200 m. altitude erupted in the same period and are immediately posterior to that rise. They are, in my view, lava-expansions subaerially superposed on the Eocene strata, rather than, according to Lotti, laccolitic in relation to the same. The former view is also expressed by D. Stefani, op. cit., p. 460.

2. *The Gavorrano Granite Group.* (Fig. 1, p. 137.)

About 25 km. south-east of Campiglia Marittima and midway between it and Grosseto, 10 km. from the coast, occurs at an altitude of about 100 m. the granitic mass of Gavorrano. It forms a dyke, 100 m. in thickness, in the isolated Rhætian and Liassic limestone outcrops of that locality, surrounded by an extensive, much folded, and tilted Eocene area which, together with Miocene strata, reaches from the coast to Massa Marittima.[1] The medium-grained granite of porphyritic rather than microcrystalline structure is composed mainly of quartz, orthoclase, albite, and biotite, with clusters of black tourmaline, and is traversed by a considerable vein of tourmaliniferous microgranite which reaches 50 m. in thickness. It consists of small crystals of monoclinic and triclinic felspar, quartz, some biotite and colourless mica, and small disseminated phenocrysts of tourmaline. The whole granite mass occurs under conditions precisely analogous to those of the Campiglia granite, and is, like the latter, of Post-Eocene age.

The Gavorrano mass is highly metalliferous, being not only traversed by numerous narrow ferriferous veins, but flanked both on its western and eastern margin, i.e. near Gavorrano and Ravi respectively, by considerable deposits of pyrite, while at its highest point, near Monticello, appears a vein of limonite. Both the western and eastern deposits occur partly in the granite itself, partly between it and the profoundly metamorphosed sedimentary strata, as also in the latter. At the western end of the granitic mass, in contact with the metalliferous deposits, the rock is so impregnated with iron oxide, and at the eastern end with pyrite, that the rock itself is almost eclipsed.

The principal interest of the Gavorrano group lies in its intimate granitic and metalliferous connexion and analogy not only with the Campiglia group but with the equivalent rocks and deposits of Elba, equidistant 35 km. from the two mainland groups. This intimate connexion is, moreover, confirmed by the fact mentioned by Lotti [2] that the Miocene conglomerates in the vicinity, i.e. east of Gavorrano, contain, amongst others, pebbles of porphyritic granite and quartz porphyry, which rocks of Tertiary age exist in Elba but not now on the mainland littoral. The pebbles, therefore, must either have been transported from Elba, or represent rocks which, formerly in situ on the mainland and removed by denudation, were of the same Tertiary age as the present, closely correlated granite of Campiglia and Gavorrano.

3. *The Montecatini and Orciatico Groups.* (Fig. 2, p. 137.)

Of the same age and of much the same composition as the trachytes of the more southern groups are the two trachytic outcrops of

[1] In this region, too, as in that of Campiglia, and also in Elba, the marine Pliocene is submerged and therefore conspicuous by its absence.

[2] Op. cit., p. 295; also E. Marocchi, "Granito di Gavorrano": Mem. Soc. tosc. Sc. nat., 1897.

Montecatini in the Cecina Valley and of Orciatico 5 km. to the north, on the divide between the Cecina and Era Valleys. These two isolated masses constitute the most northern points in the zone of volcanic activity parallel to the Tyrrhenean littoral. Both occur in the immediate vicinity of the ophiolithic masses of the Cecina Valley described in the preceding paper, and lie more or less on the contact line of the Eocene and Pliocene strata which flank them on the west and east respectively. Both outcrops form rocky eminences, the southern being surmounted by the castle of Montecatini (400 m.), the northern, or Poggio dell'Annunziata (300 m.), being near the castle and village of Orciatico. Both outcrops are skirted by roads leading to Volterra, distant about 10 km. to the east.

The grey trachyte of Montecatini is composed of a holocrystalline groundmass of sanidine, oligoclase, augite, olivine, vitreous particles, and copiously disseminated biotite, with some small nodules and inclusions of accessory quartz and pyrite. It is essentially an augite-biotite trachyte.

The Orciatico trachyte is essentially of similar composition, in two principal varieties with intermediate passages, one variety grey, holocrystalline, with phenocrysts of sanidine, augite, olivine, and biotite, partially vitreous, and cavities filled with calcite, the other brownish black, more compact and of basaltic aspect, containing more olivine. In the upper parts of the outcrop the rock is more or less altered or pumiceous. The Orciatico trachyte contains 56 to 57 per cent silica [1]; both it and by analogy the Montecatini rock come, therefore, nearest to the basic trachyte of Radicofani.

Along the contact of the trachytic masses with the sedimentary strata the latter are in several parts, notably on the eastern margin, highly silicified, spherulitic, and indurated almost to diaspri. The fact that this alteration appears not only in the Eocene argillaceous schists but also in the Pliocene fossiliferous marl, shows the volcanic outcrops to be Post-Pliocene, like those of Mte. Amiata, Radicofani, and Roccastrada. Both are effusive and subaerial, and probably formed originally one single, domal volcano, the lava streams between the two extremities having later been removed by denudation.

IV. Conclusion.

1. The five trachytic groups described in the foregoing exhibit a remarkable concordance and uniformity of mineralogical composition, as well as of structure and colour. Sanidine and plagioclase as felspathic, pyroxene, olivine, and biotite as ferro-magnesian constituents are present in them all, with or without quartz, as

[1] Two analyses by A. Martelli, Boll. Soc. geol. ital., 1909, p. 419. Earlier contributions are those by G. Vom Rath, op. cit., 1865; H. Rosenbusch, N. Jahrb. Min., 1880; G. Ristori, Proc.-verb. Soc. tosc. Sc. nat., 1887; L. Chelussi, Boll. Soc. geol. ital., 1896, p. 85; C. De Stefani, "Vulcani spenti": ibid., 1891, p. 449; B. Lotti, Boll. R. Com. geol., 1885, p. 254, and op. cit., 1910, p. 343.

essential elements. In structure the rocks vary from vitreous to microfelsitic, microcrystalline, and porphyritic, in colour from grey to brown and black, yellow, reddish, and brick red. Their micro-petrographic features alone do not admit of a satisfactory classification; the determining basis is that of their chemical composition, above all their percentage of silica. The striking variations of the latter are shown in the following table which divides the rocks into basic and acid, and also summarizes the other leading characteristics :—

TRACHYTIC ROCKS OF THE TUSCAN SUBAPENNINES.

	SiO_2 p.c.	*Spec. Grav.*	*Felspar.*	*Basic.*	*Structure.*	*Colour.*	*Age.*
1. Radicofani	54 to 55	2·75	Sanidine and plagioclase.	Augite-olivine trachyte and andesite.	Vitreous, microfelsitic, microcrystalline, and porphyritic.	Grey to brown and black. Yellow to reddish and brick-red.	Post-Pliocene.
2. Montecatini and Orciatico	56 to 57	2·68		Augite-biotite trachyte and trachyandesite.			do.
				Acid.			
3. Mte. Amiata	60 to 67	2·60		Hypersthene-biotite trachyte and andesite.			do.
4. Roccastrada	71 to 73	2·62		Quartz-biotite-cordierite trachyte.			do.
5. Campiglia	70 to 74	2·55		Quartz-biotite-cordierite trachyte.			do.

The trachytic, Post-Pliocene rocks of the island of Capraja [1] (60 km. west of Campiglia Marittima), i.e. the predominant pyroxenic andesite, and the subordinate olivinic andesite of that group belong to the Tuscan acid and basic categories and correspond to the Mte. Amiata and Radicofani rocks respectively.

The Tuscan trachytic rocks thus vary in silica from 54 to 74 per cent; in specific gravity, in inverse ratio, from 2·75 to 2·55, mean 2·63. If a regional and collective term be desirable, it should be Tuscanites, basic or acid.[2]

[1] The rocks of Capraja were petrographically described by H. Emmons, Quart. Journ. Geol. Soc., 1893, xlix, p. 129 et seq.

[2] S. H. Washington ("Italian Petrol. Studies": Journ. Geol., 1896–7) terms the Amiata, Roccastrada, and Campiglia acid trachytes *Toscanites*, the basic rocks *Ciminites*, the Amiata andesite (60 p.c. silica) a basic *Vulsinite*, collectively Trachydolerites, or, according to V. Sabatini ("Vulcani Cimini": Mem. descr. R. Com. geol., 1912, p. 348), Trachyoligoclasites. In my view, the regional terms Ciminites and Vulsinites (Viterbo and Bolsena regions) should be restricted to their own regions as *Romanites*. Moreover, Sabatini (op. cit., p. 361) points out that Washington's typical Vulsinite is in situ not in the Bolsena group, but near Vertralla (Viterbo), and is therefore a Ciminite with 57·32 p.c. silica. Washington's divisions are: Ciminites (basic) 50 to 60 p.c.; Vulsinites (medium) 60 to 64 p.c.; Toscanites (acid) 64 to 75 p.c. silica.

2. The fact that each of the five trachytic groups presents two or three principal varieties of rock, i.e. vitreous, microfelsitic or micro-crystalline, and porphyritic, all of similar composition and exhibiting fluidal structure, points to several successive subaerial, more rapidly or more slowly consolidating and crystallizing effusions of lava having taken place in each case substantially from the same magma, in the course of one single phase or period of volcanic activity. The five groups represent essentially fissure- as distinguished from crater-volcanoes.

3. All the five trachytic groups, as also the correlated island group of Capraja, are of Post-Pliocene, i.e. of Quaternary age. The laccolitic, granitic masses of the Botro ai Marmi glen, Campiglia, and of Gavorrano, closely related to the equivalent eruptive granite and quartz-porphyry masses of Elba, are, like the latter, Post-Eocene, i.e. Early or Middle Miocene, these three groups probably forming a continuous submarine complex, whose intervening area between the mainland and Elba is submerged.

4. The trachytic groups of the Tuscan Subapennines mark a period of volcanic, mainly effusive, subaerial activity of a sporadic character towards the close of the great Quaternary period of subaerial eruptions in the Bolsena, Viterbo, and Bracciano regions down to the Lazio Hills near Rome. Thus the axis of eruptive subaerial activity extended in Post-Tertiary times continuously fron north to south in a direction more or less parallel to the present Tyrrhenean littoral.

XIV.

The Crystalline Formations and Geological Structure of Elba.

In the preceding papers on the Permian and Triassic, the Ophiolithic, and the Trachytic and Granitic Groups of the Tuscan Subapennines I referred incidentally to the close geological connexion of that varied and interesting region with the Tuscan Archipelago, and more especially with the nearest, largest, and most important constituent of the same—the island of Elba.

The remarkable, in many respects unique geological and petrological features of Elba, no less than its famous mineral deposits, have been a favourite field of scientific investigation ever since 1833, when Professor Savi of Pisa, the father of Tuscan geology, published his work on that island.[1] Apart from an abundance of memoirs by Italian and other authors down to the present time, dealing with single specific points or parts, the more recent outstanding works are the three by Vom Rath, Cocchi, and Lotti,[2] the last-named with an excellent survey-map of 1886. Within the last few years a new impulse has been imparted to the tectonic and stratigraphical part of the subject by Termier, who, in a remarkable memoir of 1910,[3] advanced a bold and novel interpretation of the structural phenomena of Elba as being the result of extensive exotic overthrusts. A few years later, in 1912,[4] he applied the same theory, in correlation with Elba, and in an even more developed form, to the crystalline massif of the Savona Hills in Western Liguria, with which region I dealt in a recent paper on the Contact-Zone of the Alps and Apennines.[5]

In the present paper I propose to briefly describe, from personal study and observation, the leading geological and petrological features of Elba, more especially in relation to the crystalline rocks of the three main groups which constitute that island, and then to examine Termier's tectonic overthrust theory, under the following heads :—

I. General Features of Elba.
II. The Western Group.
III. The Central Group.
IV. The Eastern Groups.
V. The Geological Structure of Elba.
VI. Conclusion.

[1] P. Savi, "Costituzione geol. Isola d'Elba" : N. Giorn Lett., 1833.

[2] G. Vom Rath, "Die Insel Elba" : Zeitsch. D. Geol. Ges., 1870. J. Cocchi, "Isola d'Elba" : Mem. descr. R. Com. geol., 1871. B. Lotti, ibid., 1886 ; also abstracts in "Geologia della Toscana" : ibid., 1910. Lotti's map 1 : 50,000 is still the best of the island.

[3] P. Termier, "Tectonique de l'Ile d'Elbe" : Bull. Soc. géol. France, 1910, p. 134, preceded by three preliminary Notes in Comptes Rendus Ac. Sc., 1909

[4] P. Termier & J. Boussac, "Massif Crystallin, Ligure" : ibid., 1912, p. 272.

[5] *Vide* Part I of this volume.

I. General Features. (Figs. 1, p. 159 ; 2, p. 161.)

Situated 10 km. from the nearest mainland promontory of Piombino, the island of Elba covers about 240 sq. km., its length along its central axis west to east being 27, and its greatest width 10 km. Its two lowest and narrowest transverse parts in the centre, north to south, of 4 km. each, between the deeply indented Bays of Portoferraio and Stella, and of Procchio and Campo respectively, mark the division of the island into three main groups, i.e. :

(1) The Western, roughly circular, mainly granitic, and dome-shaped Group of Mte. Capanne, which latter, the highest point of Elba, reaches 1,019 m. in altitude, and is fringed around its base by Eocene sedimentary, metamorphic, ophiolithic, and porphyritic masses.

(2) The Central Group, between the two low and narrow transverse depressions already mentioned, and composed of hills not exceeding 380 m. altitude in Mte. S. Martino and Mte. Orello, the rocks being prevalently sedimentary Eocene, ophiolithic, and porphyritic.

(3) The Eastern Groups, whose highest points are Mte. Grosso in the north (447 m.), Cima del Monte about midway (516 m.), and Mte. Calamita in the south (415 m.), the area comprising Palæozoic mica- and gneissic schists largely developed in the south and in the middle ; and Permian, Rhætian, Liassic, and Eocene strata with granitic, ophiolithic, and porphyritic rocks in the north. In these eastern groups, mainly along the east coast, lie the famous ferriferous deposits, already worked by the Romans, of Rio Albano and Rio Marina in the Permian, and of Terranera (Longone) and Calamita in the mica-schist and dolomitic limestone formations respectively, with smaller pyroxenic-ferriferous and ferro-calciferous deposits near and between those localities.

The superficial area of the western and central groups is about 70 sq. km. each, that of the eastern groups about 100 sq. km. In the western and central parts of the island the main axis or divide of the northern and southern watersheds, running west to east, is intersected by the two transverse depressions, previously mentioned, of the Pila and Valdana Valleys respectively, with a low saddle on the divide of each depression. In the eastern part, on the other hand, the divide, as also the general direction of the sedimentary and infolded ophiolithic formations, runs at right angles to the western and central crest line, i.e. north to south. The southern, Palæozoic schists forming the massif and peninsula of Capoliveri and Cape Calamita constitute the geologically oldest part of the island. This southern massif is separated from the northern, more recent Mesozoic and Tertiary formations by the transverse depression of Mola and the Mar di Carvisi Valley between the Bays of Longone and Stella.

The three transverse depressions or valleys of erosion, as well as the beaches of the Portoferraio and Procchio Bays in the north, and

of the Stella, Acona, and Campo Bays in the south, all silted up and raised above sea-level, are of special interest in relation to Quaternary marine deposits. These, in the form of arenaceous conglomerate and concretionary, fossiliferous limestone, or *panchina*, like those on the Tuscan mainland coast, occur in various parts of the island, notably along and above the coastline in the eroded valleys and on the coastal slopes up to 50, 100, and, e.g. near Capoliveri in the south-eastern peninsula up to 200 m. above the present sea-level. These deposits thus show that in early Quaternary times the transverse depressions, the beaches, and the lower valleys were still submerged, and that since then the island has, like the Tuscan mainland littoral, risen several hundred metres above sea-level.

In the interior of the island, the roads along the three transverse depressions, as well as the coastal road from Portoferraio to Marciana in the central and western parts,[1] and that from Porto Longone to Rio Marina and Cape Cavo in the north-eastern part, as also the numerous bridle-paths along the south coast and across the different ridges throughout the island, afford a multiplicity of fine exposures for geological examination, and the same applies to the glens and gullies of the numerous but insignificant and intermittent streams. But most of the magnificent natural sections exhibited by the rugged points and headlands on the north and south coasts, as also those of the precipitous west coast with its imposing intrusive and other eruptive phenomena, can best be seen and reached from the sea. To these reference will be made in the description of the three geological groups of the island.

II. The Western Group. (Figs. 1, p. 159 ; 3, p. 161.)

The great dome-shaped massif of Mte. Capanne, which covers about 70 sq. km. and reaches over 1 km. in vertical depth, occupies practically the whole western part of Elba, and is for three-fourths of its circular, mainly sea-bound area composed of the classic Elban granite. The rest is represented by a narrow, intermittent, sedimentary, metamorphic, and ophiolithic belt not more than 1 km. in superficial width on the eastern, southern, and western margin, and by the similar, more extensive, and also porphyritic masses of Marciana on the north-western littoral. Owing to the great uniformity of the granitic massif as the substratum, the geological structure of Mte. Capanne is comparatively simple. The granite underlies, and is intrusive in the marginal sedimentary and ophiolithic belt, which is probably only the remnant of a much more extensive, now denuded area. In the upper parts and the crests of Mte. Capanne the granite is essentially massive and forms peaks and crags ; on the lower flanks the superincumbent pressure has rendered the rock pseudo-stratiform, and the more rounded

[1] Several of these roads, the first in the island, were constructed under Napoleon's régime during his residence in Elba, 1814.

Sketch-map of the Island of Elba. Fig. 1.

MS = Permo-Carboniferous Gneissic and Mica Schists; Pm = Permian; L = Lias; Eo = Eocene; M = Metamorphic Eocene; G = Granite; P = Quartz-Porphyry and Microgranite; O = Ophiolithic rocks (serpentine, euphotide, diabase).

surfaces often support semi-detached blocks as the effect of disintegration and denudation.

1. *The Crystalline, Sedimentary, and Metamorphic Rocks.*

The Granitic Rocks of Mte. Capanne present three principal facies, i.e. the predominant normal, the granulitic and pegmatitic, and the microgranitic. These three facies with their sub-varieties are closely related and form passages to the quartz poprhyry which constitutes an important feature in the western, central, and north-eastern parts of the island.

The well-known *normal* granite is medium-grained and composed of orthoclase, abundant plagioclase (albite and oliogclase) with micro-inclusions of apatite, abundant biotite, and quartz with liquid inclusions. Some varieties exhibit small groups of black tourmaline with a rim of micro-felspar, also cordierite, zircone, and occasional hornblende and magnetite.

The *granulitic* and *pegmatitic*, always tourmaliniferous facies appears as intrusive veins both in the normal granite and in the sedimentary and ophiolithic rocks. This facies, which often becomes micro-granulitic, exhibits substantially the same composition as the normal, but contains, in addition, muscovite, garnet, and a whole series of accessory, rare, and beautifully crystallized minerals, such as adular, beryl, topaz, and others, notably where this facies forms intrusive veins in the normal type. The pegmatitic facies, of the same composition as the normal, contains large orthoclase twins which at Cape S. Andrea on the north-west coast measure up to 20 centim. in length.

The clear white *microgranitic* facies, also called porphyritic aplite [1] and eurite, forms compact masses and also intrusive veins in the normal granite, more especially in the hills along the north-west coast. The rock, of micro-granulitic structure, consists of micro-crystals of orthoclase, plagioclase, some biotite, quartz in granules, and also disseminated as crystals, and rounded nodules of tourmaline. This facies exhibits so much affinity with the normal granite on the one hand and the quartz porphyry on the other, that it may be considered a variety of either, or a passage between the two.

The Quartz Porphyry overlies the granite on Mte. Capanne in various isolated masses as remnants of a more extensive eruptive sheet, and also forms lenticular intercalations in the same, as well as dykes and veins in both the sedimentary and ophiolithic rocks. It consists of a cryptocrystalline, occasionally rather felsitic ground-mass with porphyritic phenocrysts of orthoclase, plagioclase, biotite, and quartz with liquid inclusions, accidental minerals being apatite, zircone, and radially grouped tourmaline. Between this quartz-porphyry and the normal granite there are various passages of

[1] R. V. Matteucci, "Roccie porfiriche dell' Isola d'Elba": Mem. Soc. Tosc. Sc. nat., 1898. P. Aloisi, "Rocce granitiche negli scisti parte orientale Elba": ibid., 1910.

Sections of Elba.

Figs. 2–7.

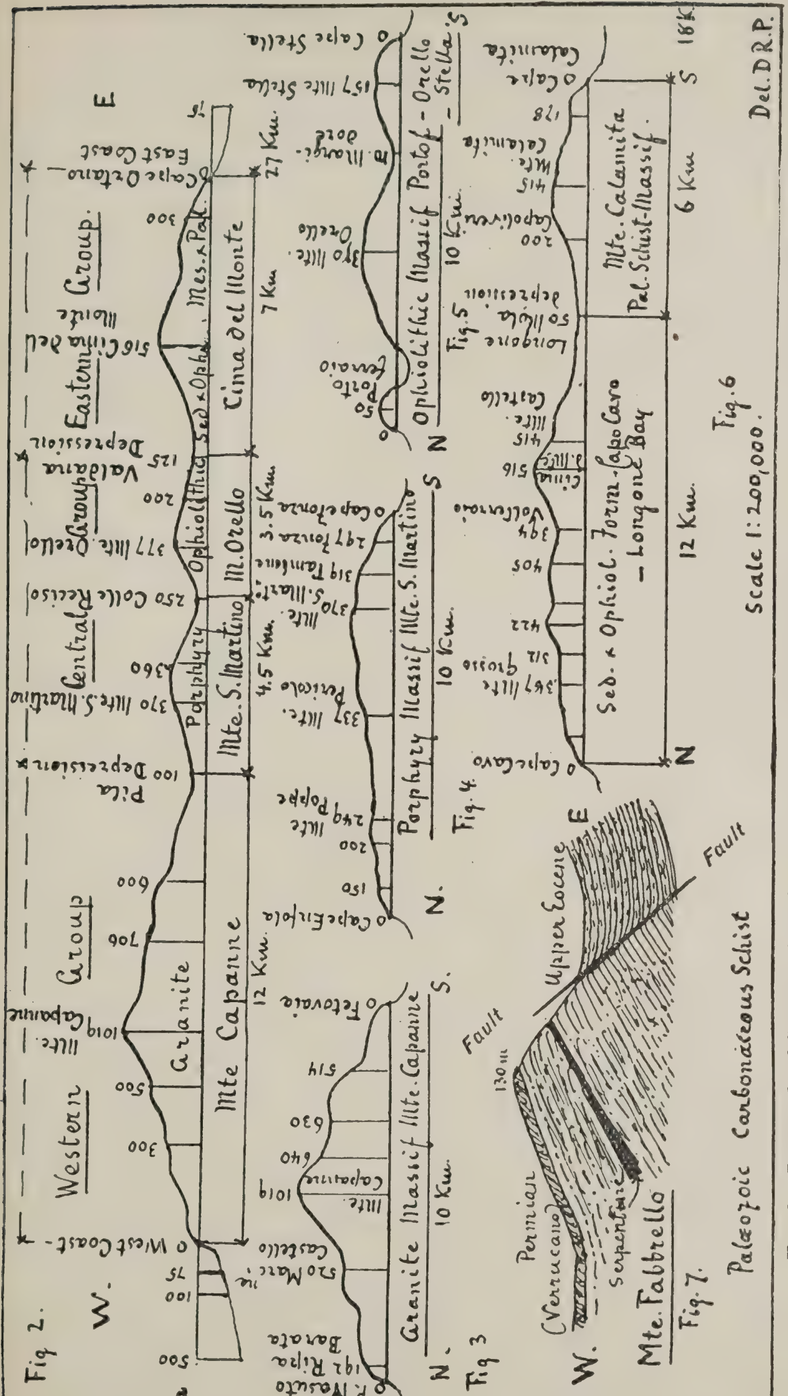


FIG. 2.—Longitudinal Section W. to E. FIGS. 3–6.—Cross Sections N. to S. FIG. 7.—Section Mte. Fabbrello.

porphyritic granite and granitic porphyry according to the predominance of one structure or the other.

The percentage of silica in these different facies of felspathic rocks varies in the normal and pegmatitic granite from 67·49 to 71·58 per cent; in the microgranite from 73·90 to 77·11 per cent, and in the quartz-porphyry from 75 to 76 per cent.[1] The microgranite is thus the most acid rock of the four. The difference between them is not one of mineralogical composition, but essentially of structure. The three facies intrusive in the normal granite erupted somewhat later than the latter; but they all obviously proceeded from the same magma, consolidating and crystallizing in successive stages, and are of the same Post-Eocene age, as is shown by fragments of Eocene sedimentary rocks in the intrusive veins and dykes throughout the massif.

The Ophiolithic Rocks of the marginal belt of Mte. Capanne consist of peridotitic and lherzolitic serpentine overlain by euphotide and diabase in the usual Tuscan sequence. The lherzolitic serpentine is in some places underlain, in others replaced by peridotitic and amphibolic, very schistose serpentine with associated green schists, containing hypersthene and magnetite. Lotti is disposed to regard these peridotitic schists as older than the lherzolitic serpentine; but as both pass into each other and both occur below the Eocene euphotide and diabase, and in the Eocene strata overlying the granite they are, in my view, both of the same Eocene age. The schistosity of the peridotitic rock is due to pressure and more advanced alteration by hydration. Their affinity and graduation into each other points to their being the product of the same magma.

The Sedimentary and Metamorphic Rocks.—The sedimentary rocks of the Mte. Capanne group comprise the usual albarese limestone, galestri schists, and macigno sandstone of the Lower and Upper, so-called promiscuous Eocene (fucoids) series, and rest in some places direct on the granite, in others on the ophiolithic rocks, or again appear between the two. A peculiar, non-fossiliferous formation is that of the metamorphic series of indurated, semi-crystalline diaspri, crystalline limestone and cipollini, micaceous, calcareous, arenaceous, chloritic and spotted schists largely converted to hornfels, as also quartzose and gneissiform schists, all of which form considerable banks and bands between the granite and the ophiolithic rocks of the marginal belt. The hornfels, composed of a granular groundmass with microcrystals of epidote, augite, and hornblende, and the gneissiform schists, appear more especially in contact with the granite.

These metamorphic rocks have been variously interpreted in part as Pre-Silurian, in part as much more recent, in part, i.e. as regards the gneissiform schists, as altered granite. But their occurrence

[1] These percentages of silica are the averages of ten different analyses collected and published by V. Novarese in Boll. R. Com. geol., 1910, p. 212. The analyses are by Aloisi (1910), D'Achiardi (1902 and 1904), Manasse (1900), Bunsen (1861), and Damour (1851).

in association with the Eocene sedimentary and ophiolithic rocks warrants their all being of the same Eocene age, their metamorphism being due first to induration by contact with the eruptive ophiolithic rocks, and later to enhanced silicification and semi- or total crystallization by contact with the eruptive granite, while the quartzose and gneissiform schists are probably the product of granite crushed, compressed, altered, and laminated by pressure. Both the sedimentary and ophiolithic series contain considerable dykes, and are traversed by numerous veins and apophyses of granite and quartz-porphyry, the former predominantly in the lower, the latter in the upper strata and masses. It is a noteworthy feature that the alteration of the Eocene sedimentary strata is much more pronounced in contact with the granite than it is in contact with the somewhat later quartz-porphyry veins and dykes.

2. *The Marginal Belt.*

The sedimentary, metamorphic, ophiolithic, and porphyritic belt which intermittently encircles the base of the granitic dome of Mte. Capanne, may be divided into six sections occupying in the aggregate 24 km. out of the 36 km. or two-thirds of the total circumference of the roughly circular massif. Of the total circumference only one-third, i.e. the eastern base, is contiguous to the transverse depression of the Pila Valley between Procchio near Procchio Bay and that of Campo Bay on the north and south coasts respectively ; the other two-thirds, on the south, west, and north, are sea-bound. On land the coast can be followed all round by bridle- or foot-paths, while the Pila Valley, with the geologically important district of S. Ilario and S. Piero on the lower eastern slopes of the Mte. Capanne massif, is easily accessible by road. The salient features of the six sections of the marginal belt are briefly described in the following paragraphs, proceeding round the base of the massif from Punta Fetovaja, the extreme south-western point of the coast, northward.

(1) *Punta Fetovaja to Pomonte*, 4 km.—The low, elongated promontory of Fetovaja is composed mainly of much decomposed euphotide with diabase veins. Near Fetovaja itself, about one km. from the Point, the Eocene strata are traversed by numerous veins of granite, a fact which was first established by Dalmer and conclusively confirmed the Tertiary, i.e. Post-Eocene, age of the Elban granite.[1] The same locality exhibits in upward succession, and overlying the granite, peridotitic schists reduced to magnesite, locally called kaoline, and greatly altered euphotide ; then Eocene sedimentary strata, upon which follows a mass of lherzolitic serpentine overlain by euphotide and diabase in the usual order of superposition. Further on, towards Pomonte, on the west coast, the marginal belt

[1] K. Dalmer, "Insel Elba": Zeitsch. Naturwiss., 1884. "Das Alter der Granit and Porphyr Gesteine Elba": N. Jahrb. Mon. Geol., etc., 1894.

consists mainly of lherzolite and lherzolitic serpentine and the overlying metamorphic series. Near Pomonte the lherzolitic serpentine is replaced by peridotitic, schistose serpentine which generally forms the lowest member of the ophiolithic series and is an emanation of the same basic magma, the rock having become schistose by hydration and pressure.

(2) *Pomonte to Punta Polveraja*, 5 km.—This section extends along the west coast by Chiessi and Punta Timone, and is composed of large masses of peridotitic serpentine and metamorphic rocks resting on and against the granite substratum. The granite here forms veins and apophyses in the serpentine, while large dykes and lenticular masses of quartz-poprhyry occur in the overlying metamorphic rocks, near Chiessi also in the granite. Near Pomonte, Punta Fornace, and Punta Polveraja occur in the serpentinous rocks the famous Elban specimens of epidote and garnet. In the same section, between Punta Timone and Punta Fornace, occur in the metamorphic rocks stupendous veins and dykes of tourmaliniferous granite, pegmatite, and quartz-porphyry, here also with remarkably fine crystals of garnet. From Punta Polveraja to Capo S. Andrea, the north-western extremity of the island, and thence to Punta Cotoncello, the coast only exhibits granite, often porphyroid; with pegmatitic veins.

(3) *Punta Cotoncello to Marciana and Bagno*, 7 km.—This, by far the largest section of the marginal belt, comprises, along the north coast, the conspicuous intermediate points La Conca, Punta Nasuto, and Ripa Barata west of Marciana Marina, and Punta Crocetta and Punta Schioppo east of that place. At its western end, i.e. at Marciana Castello, it reaches up to 500 m., and at its eastern end, i.e. on Mte. Perone and Mte. Maolo, up to 700 m. altitude, and including the intervening slopes of the Nivera Valley, covers an area of 25 sq. km. On the left or western side of that valley and its alluvial plain or former fjord, extends a large area of quartz-porphyry with considerable lenticular intercalations of yellowish microgranite, notably at Mte. Ripa Barata ; on its western margin this area is flanked by a belt of metamorphic rocks which expands to a large mass at Punta La Conca ; and this latter is, in its turn, flanked by the peridotitic serpentine fringe of Punta Cotoncello.

The metamorphic mass exhibits several dykes of intrusive quartz-porphyry both on the coast and more inland on the slopes ; it fringes the great porphyry mass also at Marciana Castello, which last-named place is, like the village of Poggio on the opposite side of the Nivera Glen, built on Mte. Capanne granite. Below Marciana Castello, at Piano S. Lorenzo, between the Nivera and the great porphyry area, is wedged a mass of diabase which has, by erosion, been separated from the large ophiolithic area on the right or eastern side of the valley. Here a large diabasic mass which exhibits nodules and incrustations of epidote, overlies a smaller mass of euphotide and, below the latter, a considerable mass of peridotitic serpentine. This serpentine extends to the coast at Bagno, and, inland, towards

Mte. Capanne, up to Mte. Maolo at 700 m. altitude as already mentioned. The diabasic mass, in its turn, extends along the coast from Marciana Marina to Punta Crocetta and Punta Schioppo, and in this section is in part overlain by a large mass of quartz-porphyry. The latter has, like the diabase, been separated from the mass on the left side by the erosion of the Nivera Valley. Several other smaller masses of quartz-porphyry crop out in the ophiolithic area, all of which also exhibit intrusive veins, e.g. near Punta della Madonna di Marciana, where, in an exposure close to the sea-level, a mass of euphotide and overlying diabase is traversed by apophyses of the adjacent mass of porphyry. A magnificent vein of white quartz-porphyry traverses the diabase at Punta Schioppo close to the sea-level, and forms one of the finest natural sections on the north coast of the island.

The diabase of the Marciana group appears both as massive, aphanitic, and as spheroidal, in part variolitic ; it forms, as usual, veins in the underlying euphotide which in this ophiolithic group is exceptionally fresh and unaltered. The serpentine passes at its base to peridotitic and amphibolic schist, as it does near Fetovaja and in other parts of the marginal belt. Here too this schist is, in my view, simply the crushed and laminated derivative of the original peridotitic rock, the alteration being due to pressure. The whole Marciana group of metamorphic, ophiolithic, and porphyritic rocks rests on the Mte. Capanne granite as substratum. The road along the coast from Bagno to Marciana Marina and that along the Nivera Valley and up the glen to Poggio on one side and to Marciana Castello on the other afford in succession a large number of interesting and instructive exposures of this, one of the most remarkable crystalline groups of Elba.

(4) *Punta Sprizze to Punta Agnone and Pila*, 4 km.—This section, mainly of metamorphic rocks, extends from near Bagno along the north coast to the islet Isolotto and Punta Agnone, the western headland of Procchio Bay, and thence inland along the western margin of the transverse depression to near Pila in the valley of that name. The metamorphic rocks of this section form a continuous belt at the base of the Mte. Capanne massif, and are throughout traversed by granitic and porphyritic veins.

Along the north coast, from Punta Sprizze to Procchio Bay, the metamorphic rocks are predominantly composed of greenish calcareous, chloritic, and micaceous schists, crystalline cipollini, and nodulous quartzite with intrusive veins of granite. A remarkable intrusive phenomenon occurs in the islet Isolotto, where thin veins of tourmaliniferous granite traverse both the metamorphic schists and a dyke of quartz-porphyry encased in the latter. The normal porphyry is here altered to a microcrystalline rock of an essentially quartzose and felspathic groundmass with micro-phenocrysts of quartz, mica, and tourmaline. Another remarkable exposure is that at and near the neighbouring Punta Agnone, where the schists are

converted to hornfels and diaspri, and limestone is rendered crystalline by contact with intrusive granite veins whose contact lines exhibit inclusions of aggregations of garnet.

From Punta Agnone to Pila banks of diaspri rest on compact, greenish, grey, and white, partly indurated limestone which, in its turn, is underlain by varicoloured schists. The lower strata of these rocks are traversed by granitic, the upper more by porphyritic veins, here too with garnet aggregations at and near the lines of contact. The Pila Valley, which, as already mentioned, forms the depression between the western and central groups of the island, slopes from the low dividing saddle of about 100 m. altitude down to Campo Bay on the south coast and lies in the Upper Eocene horizon. The latter, largely removed by erosion, is here reduced to low, denuded spurs which project into the valley at right angles and are mainly composed of banks of "pietraforte" macigno sandstone, the eroded gaps between them being, like the floor of the valley, filled with alluvial deposits. The margins of those macigno banks are skirted by isolated masses of quartz-porphyry, on one of which the village of Pila is built. These outcrops on the right of the valley obviously formed part of the great porphyritic area on the left from which they were separated by erosion.

(5) *Pila to S. Ilario, S. Piero, and Punta di Cavoli*, 4 km.—This section, geologically one of the most interesting and important of the marginal belt of Mte. Capanne, is mainly composed of masses of lherzolite, serpentine, and euphotide, with underlying peridotitic schists which rest upon the granite base flanked by the Eocene strata of the Pila Valley. The ophiolithic masses are, in contaet with the granite, largely decomposed to magnesite, which is extensively quarried. The classic localities of S. Ilario (260 m.) and S. Piero (130 m.), as well as Colle Palombaia near the south coast, and the intervening hills owe their geological celebrity at once to the extraordinarily developed granitic veins, dykes, and lenticular intercalations in the ophiolithic masses, to the intrusive veins and dykes of microgranite and pegmatite in the granite itself, and to the geodes of beautiful garnet, wollastonite, and other perfectly formed crystals which the intrusive phenomena have produced.

Between S. Ilario and S. Piero, in a mass of lherzolite and lherzolitic serpentine, appears a lenticular intercalation of remarkably fresh and beautiful garnetiferous euphotide tending to eclogite, whose greenish and pinkish garnetiferous and saussuritic base exhibits large phenocrysts of smaragdite. The serpentine passes to the underlying peridotitic and amphibolic schists which, in their turn, become gneissiform at the contact with the granitic substratum, while the latter itself here assumes a gneissiform schistose structure. This group thus presents the same phenomenon of the gradual downward passage of lherzolitic serpentine to peridotitic schist, gneissiform schist, and gneissiform schistose granite to the normal granite as in the Marciana group. In both cases the schistosity of the ophiolithic

rock and that of the laminated gneissiform-granitic schist is due to pressure and crushing ; it does not, in my view, warrant these schists being considered older than, or separate from, the overlying Eocene ophiolithic rocks or the granitic substratum, of which they are simply Post-Eocene modifications by hydration and pressure.[1]

Further south, on the coast, at Colle Palombaia and Punta di Cavoli, appears, overlying the granite, another mass of metamorphic rocks composed in part of crystalline calcareous schist and diaspri with white and pink crystals of wollastonite, in part of micaceous, quartzitic, and gneissiform schists in close association with gneissiform, i.e. altered and crushed granite and microgranite. The intrusion of the latter rocks has produced the beautiful crystals or "tears" of drop-quartz with curved facets and concentric structure for which this locality is famous. It is a noteworthy fact that neither the non-metamorphic Eocene strata flanking the eastern base of Colle Palombaia nor those at the base of the neighouring Mte. Turato exhibit at the contact of the granite and the quartz-porphyry respectively, any notable alteration, except slight silicification. This fact applies also to the non-metamorphic sedimentary Eocene strata in other parts of the marginal belt, whereas the ophiolithic masses are invariably more or less profoundly altered and largely reduced to magnesite.

(6) *Punta di Campo to Punta Bardella.*—The coast section from Punta di Cavoli west to Punta Fetovaia, which completes the circular base of the Mte. Capanne massif, exhibits only normal granite with veins of the tourmaliniferous and pegmatitic varieties, a good quarried granite exposure being that near Sacchetto, about midway. On the other hand, east of Punta di Cavoli and Colle Palombaia towards the headland of Punta di Campo, the coast reveals several magnificent and highly characteristic intrusive phenomena of quartz-porphyry in the Eocene sedimentary banks. The most striking of these exposures are the enormous porphyry veins of Mte. Turato, as also of Cape Poro near Punta di Campo, and more especially the stupendous dykes or lenticular porphyry masses, extending, with numerous apophyses, for about one km. in the much folded limestone and argillaceous schists of the promontory from Punta di Campo to Punto Bardella in Campo Bay. Here the intrusive masses have traversed the previously folded strata without producing any contact metamorphism or stratigraphical disturbance. This phenomenal intrusive exposure has its equally imposing counterpart in the opposite eastern promontory of Campo Bay, i.e. in Cape Fonza, which forms part of the central group of the island.

3. *Origin of the Mte. Capanne Massif.*

Closely related to, and contemporaneous with, the Mte. Capanne massif are the Tertiary granitic rocks of the islands of Montecristo

[1] A short note on the ophiolithic rocks of this region was published by E. Mattirolo, "Tre Rocce di S. Piero in Campo," in Rendiconti R. Acc. Lincei, 1883.

(648 m.) and Giglio (498 m.), 45 km. south and 55 km. south-east from Elba respectively, as well as the two mainland granitic groups of Campiglia Marittima and Gavorrano, the last-named with quartz-porphyry, as described in a previous paper. All these groups constitute parts of the former Miocene Tyrrhenean Continent. In and around the Mte. Capanne massif, as also in the island- and mainland groups mentioned, the Pliocene marine formation has entirely disappeared, except in the small island of Pianosa, 15 km. south-east from Elba, of which it constitutes the whole superficial area, barely 20 km. above sea-level. It is thus the only, but conclusive, remnant of the Pliocene formation which in early Post-Pliocene times was submerged during the partial subsidence, in successive stages, of the Tyrrhenean Continent. Similarly, the marginal, sedimentary, and ophiolithic belt of the Mte. Capanne massif represents the remains of a much larger Eocene formation, submerged at the same time. The granitic rocks of Mte. Capanne throughout the massif invariably underlie the Eocene sedimentary, ophiolithic, and metamorphic rocks which are of submarine origin. The granitic and porphyritic masses must therefore have erupted and consolidated below those formations, and must have broken through them during the great general Miocene uprise. It was thus that Mte. Capanne emerged and rose as an imposing Post-Eocene dome-shaped granitic massif of essentially laccolitic origin, with the sedimentary, ophiolithic, and metamorphic belt resting upon it around its base. Its original height and the area of the marginal belt were lowered during the partial submergence of the Tyrrhenean Continent in the early Post-Pliocene, after which it experienced in the last Quaternary a new gradual uprise of 100 to 200 m. to its present level above the sea.

III. The Central Group. (Figs. 1, 2, 4, 5, pp. 159, 161.)

In striking contrast to the western or Mte. Capanne group, the central group presents very broken and deeply indented contours, mainly due to its being composed entirely of porphyritic, Eocene sedimentary, and ophiolithic masses, of which only the last-named offer a considerable degree of resistance to erosion, denudation, and the incursions of the sea. The more easily disintegrating porphyry and also the sedimentary, mainly calcareous, and the diabasic masses of the low hills account for this central group being, together with the Marciana Valley on the north-west coast, the best watered, wooded, and cultivated part of Elba. The enormous masses of quartz-porphyry which by their intrusion have profoundly disturbed and dislocated the Eocene strata, occupy the greater part of the western and northern area of this group, while the sedimentary formation, largely composed of albarese limestone, galestri schists, and macigno sandstone of the Upper Eocene series, predominates more in the middle part, and the ophiolithic masses of Portoferraio, Mte. Orello, and the Stella promontory constitute the eastern part. As previously stated, this central group is bounded west and east by

the two transverse depressions of the Pila and Valdana Valleys respectively, while on the north coast it is deeply indented by the Bays of Procchio and Portoferraio, and on the south coast by the Bays of Campo, Acona, and Stella.

1. *The Porphyry Groups of Mte. S. Martino and the North Coast.*

(1) *The S. Martino Massif.*—The southern extremity of this great porphyry complex is formed by Cape Fonza, which, as already mentioned, constitutes the eastern headland of Campo Bay, and, like the opposite western headland of Cape Poro and Punta di Campo, exhibits close to the sea-level magnificent veins of white quartz porphyry in the Eocene strata. Both these headlands afford natural sections of some of the finest intrusive phenomena on the south coast of Elba. From Cape Fonza along the coast of Campo Bay exposures of porphyry masses and sedimentary strata alternate round the base of Mte. Tambone (379 m.), and the same applies to the eastern flanks of that hill in Acona Bay, where isolated masses of porphyry appear in banks of yellow macigno sandstone. The latter is here so disintegrated that it has lost its stratification and presents the appearance of decomposed porphyry, so much so that, being in contact with a mass of true porphyry, it was at one time erroneously regarded as porphyry tuff.

From Campo Bay along the eastern margin of the Pila Valley and thence to Procchio Bay on the north coast the quartz-porphyry forms the massif of Mte. S. Martino (370 m.), the latter being the highest point, from which spurs and isolated masses extend towards the north coast, eastward to Mte. S. Lucia, and south-east towards Acona Bay. The porphyry mass of Mte. S. Lucia with its small crown of microgranite is at its eastern margin in contact with the ophiolithic masses of Mte. Orello, and this also applies to smaller outcrops of porphyry in the Condotto ravine near Mte. Cafferi. In the area immediately east and south-east of Mte. S. Martino the Upper Eocene strata, here largely in evidence, generally occupy the flanks of the lower hills and saddles, including the Middle Eocene beds of Colle Reciso [1] and Mte. Petriciaio [1] in contact with the ophiolithic massif of Mte. Orello, while the intrusive porphyry dykes and masses mostly occupy the heights. In some places the sedimentary strata overlie, in others they underlie the porphyry, again in others they infold the porphyry or are infolded in it. In some cases, e.g. on the southern and eastern flanks of Mte. Moncione and Colle alle Vacche, in the centre of the group, the two formations alternate and are interstratified. Throughout the group the intrusive porphyry masses have profoundly folded, contorted, tilted, and dislocated the Eocene strata, without, however, producing any contact-metamorphism beyond occasionally indurating them to diaspri or forming along the contact some garnetiferous aggregations.

[1] The bridle-path from Portoferraio Bay across the island to Acona Bay leads through the Condotto glen over Colle Reciso and down the Pino glen to the south coast.

(2) *The North Coast Group.*—North of Mte. S. Martino the quartz-porphyry forms the masses of the Bays of Procchio, Biodola, and Viticcio, and of Cape d'Enfola, separated by intervening Eocene sedimentary beds, the intrusive phenomena and their disturbing effect upon the stratified rocks being the same as in the central area. From Cape d'Enfola a large area of porphyry extends 5 km. east along the coast to Punta Sansone, Punta Acquaviva, Cape Bianco, and Fort S. Claud, near Portoferraio, while more inland the area includes the considerable mass of Mte. Poppe (250 m.). Between those points the coast exhibits large masses of white tourmaliniferous microgranite traversed by porphyry veins, which latter also form the fine natural section of Punta Sansone, near Cape d'Enfola, where these veins traverse the Eocene strata. The microgranite or porphyritic aplite is, like that of Ripa Barata west of Marciana, essentially a variety of the quartz-porphyry on the one hand and of the normal granite on the other. Immediately west of Portoferraio large accumulations of white microgranite and black tourmaline pebbles derived from Cape Bianco form the beach deposits known locally as Le Ghiaie.

(3) *Origin of the Porphyry Groups.*—The quartz-porphyry of the central group of Elba varies a good deal in the different localities. Thus in the Mte. Tambone group in the south it is often spheroidal and much decomposed by atmospheric action. On and near Mte. S. Martino and in the spurs of that group, as well as on the coast in Biodola Bay and at Cape d'Enfola, as also in the Mte. Poppe mass, it is tourmaliniferous, micaceous, often also granitic with large orthoclase twins and microgranitic inclusions. Again, at Punta Penisola in Viticcio Bay, as also in the S. Lucia mass, it is granular and tourmaliniferous. In the transverse depression south of Procchio Bay, the porphyry mass on the eastern margin of the saddle reaches close to the Mte. Capanne granite of the western margin, though the two rocks are not in actual contact, but separated by an intervening strip of metamorphic rock. The various masses of quartz-porphyry of this central group of Elba are separated from each other by eroded Eocene sedimentary glens and denuded heights, with porphyry patches here and there; the masses therefore obviously formed originally an essentially continuous complex, cupoliform like the Mte. Capanne massif, though of lower altitude and extent, its area being about 40 sq. km. or about half that of the latter. It is, like that granite massif, essentially a deep-seated, eruptive, submarine formation, i.e. of laccolitic origin, its uprise with and through the Eocene sedimentary beds having taken place in Post-Eocene times.

2. *The Ophiolithic Groups of Portoferraio, Mte. Orello, and Cape Stella.*

(1) *The Portoferraio Group.*—The town of Portoferraio and its forts, situated at the western headland of the Bay of that name, are built on an ophiolithic mass with some overlying diaspri and much contorted Upper Eocene albarese limestone. The ophiolithic mass is

composed predominantly of diabase, which at the western and eastern ends is crowned by the two forts of Falcone and Stella respectively, while serpentine with some euphotide intercalations occupies the middle part which supports the town. The diabase at the Falcone end, overlain by the sedimentary rocks, is dark green and fine-grained, while that at the Stella end is normally green, more or less altered to the reddish spheroidal and variolitic type with veins of calcite, chlorite, and epidote, the last-named of which also forms geodes in the calcite veins. The serpentine, whose contact with the diabase at both ends is quite distinct, is in part lherzolitic and compact, in part peridotitic and schistose ; the intercalated euphotide is partly altered, but its contact with the serpentine, too, is quite distinct. The contact of the diabase and the diaspri is, as not infrequently elsewhere, marked by an intermediate narrow strip of serpentine schist, i.e. diabase altered to pseudo-serpentine, with dolomitic veins. Near the diabase mass of Fort Stella appears an agglomeration of serpentine-euphotide- and diabase-breccia with a green calcareous cement. Immediately west of Portoferraio near the beach of Le Ghiaie previously mentioned, an interesting natural section discloses a mass of quartz-porphyry in contact with Eocene strata and diabasic conglomerate, followed by serpentine ; at the contact the porphyry and the limestone form a mixed breccia, due to the intrusion of the porphyry. From the Portoferraio group, the most northern of the ophiolithic zone or belt which crosses the island north to south, a ledge of the same rock connects below sea-level with the opposite headland of Punta delle Grotte which forms the northern base of the Mte. Orello massif.

(2) *The Mte. Orello Group.*—From Punta delle Grotte to Stella Bay on the south coast extends uninterruptedly the great ophiolithic massif of Mte. Orello (377 m.), one of the highest points of the central part of Elba, and of Mte. Corsetti (286 m.). Near S. Giovanni, on the margin of the alluvial beach of Portoferraio Bay, the base of Mte. Orello exhibits in the hill of S. Domenico lherzolitic serpentine overlain by epidotic, yellowish grey, and stratiform diabase which is superficially so altered as to resemble weathered macigno sandstone. The same deceptive phenomenon appears on an even larger scale in the diabase of the eastern flanks of the massif.

The massif is composed predominantly of diabase with an intermittent belt of lherzolitic serpentine around its base, and a narrow parallel band of euphotide between the serpentine and the diabase in the south-eastern part. The massif is normally infolded between nummulitic limestone of the Lower and varicoloured limestone of the Middle Eocene ; the former appears in several small outcrops at the southern margin underlying the serpentine of Cape Norsi and Cape Pini in Stella Bay, and the latter overlying the serpentine and diabase along the western margin, notably in the depression and saddle of Colle Reciso and Mte. Petriciaio between Mte. Orello and Mte. Moncione. The ophiolithic massif is entirely

denuded of sedimentary rocks, and the superposition of its three constituents is normal and practically undisturbed. But at the contact on the western margin with the Eocene strata near Mte. S. Lucia and Colle Reciso in proximity to quartz-porphyry masses, the normal sequence of both the ophiolithic and sedimentary series is in several places actually reversed. Interesting phenomena due to the disturbing effect of the laccolitic intrusion of quartz-porphyry or microgranitic masses may also be observed on the south coast in the serpentine and sedimentary outcrops of Pian d'Acona, Punta Contessa, and Ghiaceto in Acona Bay, where the ophiolithic rocks are either wedged between the sedimentary strata and the porphyry or directly infolded in the latter.

The serpentine of Mte. Orello is of the ordinary lherzolitic type and the whole Eocene ophiolithic series is contemporaneous with, and strictly analogous to, that of the Tuscan Subapennines. At Punta delle Grotte in Portoferraio Bay, where the serpentine is bastitic, it contains veins and lenticular intercalations of euphotide. On the south-eastern flank of Mte. Corsetti a remarkably fine exposure exhibits the three superposed ophiolithic rocks, serpentine, euphotide, and diabase, in part adjacent to and overlain by Lower Eocene sedimentary strata. At the southern end of the massif at Cape Norsi in Stella Bay appears a remarkable section of serpentine between which are wedged thin alternating bands of Eocene limestone and sandstone with small groups of garnet along the lines of contact. The diabase of this massif, too, often contains both garnet and epidote, and notably the localities of Campo ai Peri and Campo del Margidore in the north-west corner of Stella Bay yield fine specimens of both those minerals. Other interesting natural sections exhibiting the relative position, alternations, and interposition of ophiolithic and sedimentary rocks appear at the beach of Norsi and the neighbouring Cape Pini in Stella Bay, where the contrast of colour between the dark serpentine and the white or varicoloured Eocene strata is very striking.

(3) *The Cape Stella Group.*—From the south-western end of the Mte. Orello massif at Margidore extends the promontory of Cape Stella, 2 km. in length, and 1 km. in width, which separates Stella Bay from that of Acona. It forms a ridge about 160 m. in altitude. With the exception of a few isolated Eocene sedimentary patches it is composed entirely of diabase of the same normal, in part altered spheroidal and variolitic type as that of the Mte. Orello massif of which it is the southern extension. On the rugged west coast of this promontory, i.e. at Cape Piastraio, occurs close to the sea-level a remarkably fine section of dark-green diabase encasing a mass of white and varicoloured Eocene limestone, of which some isolated outcrops overlying the diabase also appear at the southern extremity of Cape Stella. The diabasic masses of the promontory also exhibit here and there traces of thin porphyry veins as indications of formerly more extensive, now denuded intrusive phenomena. West of the

northern end of the Stella promontory in Acona Bay an interesting natural section is presented by the smaller headland of Punta della Contessa, which is composed of serpentine in contact with a mass of quartz-porphyry intrusive in Eocene strata. From this point to Cape Fonza the coast of Acona Bay is formed by the Eocene sedimentary strata and intrusive porphyry masses of the eastern flanks of Mte. Tambone, which have been already noticed and complete the round of the central group of the island.

3. *Summary.*

The Central Group of Elba described in the foregoing paragraphs is composed of three formations of submarine origin, i.e. the quartz-porphyry massif in the western part, the sedimentary Eocene beds mainly in the middle, and the ophiolithic masses in the eastern part. Of these the quartz-porphyry massif with dykes of microgranite, although separated from the Mte. Capanne granite massif by the eroded Pila Valley and depression, is intimately related to, and contemporaneous with the latter massif, both being an originally deep-seated submarine complex raised laccolitically through the Eocene sedimentary formation in Miocene times. The ophiolithic masses in the eastern part of the central group are, like those of the Tuscan Subapennines, infolded as submarine expansions in the contemporaneous Eocene sedimentary formation and represent about one-fourth of the total area of the central group. On its eastern margin this originally continuous ophiolithic massif is at its northern end contiguous to the alluvial beach formation of Portoferraio Bay ; in the middle and at its southern end it adjoins a narrow band of Liassic varicoloured schists, which latter form part of the transverse Valdana depression between the central and eastern groups of the island. It is a noteworthy feature that the general direction north to south of the ophiolithic massif is the same as that of the sedimentary strata on either side, and also as that of the sedimentary and ophiolithic formations of the eastern group, thus pointing to a correlation of the two groups, as will appear in the sequel.

IV. The Eastern Groups. (Figs. 1, 2, 6, 7, pp. 159, 161.)

Great as is the contrast between the general contour and geological structure of the Western and Central Groups of Elba, still greater is it between these two and the third or Eastern Groups. As previously pointed out, the Eastern Groups, the largest of the three divisions, cover about 100 sq. km. and are aligned north to south, that is, at right angles to the axis of the Mte. Capanne and Mte. S. Martino massifs of the Western and Central Groups. The transverse depression of Valdana between the Bays of Portoferraio and Stella, which forms the line of division between the Central and Eastern Groups, runs in the same north to south direction, and so does the axis of the ophiolithic massifs of Mte. Orello and Cape Stella, previously described.

The Eastern Groups are geologically composed of three parts :—

1. The southern group, from Cape Calamita, the southern extremity of the island, to the Bays of Longone and Stella, with an extension along the north-east coast from Longone Bay to Cape Ortano. The southern group also incudes the Hills of Capoliveri on the coast of Stella Bay.

2. The northern group, from Longone Bay to Cape Cavo, the northern extremity of the island.

3. The Valdana depression between the Bays of Portoferraio and Stella.

In its total length of 20 km. from Cape Calamita to Cape Cavo, the crest line of the Eastern Groups, interrupted only by the transverse Mola depression between the Bays of Longone and Stella, rises in the southern group to a maximum altitude of 413 m. in Mte. Calamita, and in the northern group to 516 m. in Cima del Monte, the latter being 150 m. higher than Mte. S. Martino in the Central and 500 m. lower than Mte. Capanne in the Western Groups.

1. *The Southern Group.* (Figs. 1 and 6, pp. 159, 161.)

(1) *The Crystalline Schists : Mte. Calamita Massif.*—The dome-shaped massif of the promontory of Mte. Calamita, geologically the oldest part of Elba and about 40 sq. km. in superficial area, is composed predominantly of crystalline schists. The lowest of these, forming the visible substratum, are gneissic, in part felspathic, chloritic, and often tourmaliniferous, with quartz nodules and occasional small intercalated masses of grey minute gneiss of granular structure. At the base, i.e. near sea-level, they often become granitic and in places actually pass to granite. These dark-grey gneissic schists rise to about 300 m. above sea-level and form a belt round the east, south, and part of the south-west coast. They are overlain in the centre by an enormous mass, 100 to 400 m. in thickness, of spotted felspathic, tourmaliniferous, prevalently white mica-schists with nodules and intercalations of quartz. Upon these mica-schists follows, by passages, intercalations, and alternations in the upper parts, a series of pale-green calc-mica-, i.e. sericitic schists with associated dolomitic limestone, in part compact, white and yellow, in part pink and yellow and semi-crystalline, in part white crystalline and saccharoidal. This series, 50 to 100 m. in thickness, is developed more especially at Calamita and at Capoliveri, in which latter locality it is overlain by Upper Eocene strata with intrusive masses of quartz-porphyry. On the south-west coast the dolomitic limestone also forms one of the " Gemini " or twin islets, the other islet being composed of Eocene serpentine, euphotide, and diabase, with epidotic veins and inclusions of limestone fragments. This small group points to a submarine connexion with the diabasic masses of Cape Stella. In the Mte. Calamita massif ophiolithic rocks are generally absent, except some insignificant outcrops of serpentine at Capoliveri.

The general strike of the schist formations is north-east to south-west, dipping north-west, but at Cape Calamita it abruptly changes to north-west–south-east, dipping into the sea. The planes of the schists are generally more or less horizontal, except in the south-eastern and central parts, where the schists are greatly laminated, folded, and contorted. Striking exposures of the abruptly dipping gneissic schists as the visible substratum with overlying white limestone and ferrocalciferous deposits are afforded by the natural sections of Punta Nera and Punta Bianca, the two headlands of Cape Calamita in close proximity to the iron-mines of that locality.

Longone Bay to Cape Ortano.—From the northern end of the Calamita massif the gneissic schist formation extends on the east coast all round the Bay of Longone to Cape Bianco near the iron deposits of Terranera, while from this latter point it is the upper or white mica-schists which extend as a coastal belt, about 6 km. in length and half a km. in width, to Cape Ortano and Punta Porticciolo. This mica-schist belt passes inland to an overlying, parallel, intermittent zone of crystalline limestone and cipollini which in it turn passes to a continuous, parallel zone of dull-grey sericitic schists, phyllites, or *schisti plumbei*, with quartz-nodules.

Stella Bay and Valdana.—The mica-schists predominate in the western part of the Mte. Calamita massif along the coast from Punta Pareti to Capoliveri and Spiagggia di Lido in Stella Bay and thence extend to the Valdana depression, on the eastern side of which they are separated from the gneissic schists of Longone Bay by the Mar di Carvisi glen. Between the mouth of the latter glen and Longone Bay lies the extensive alluvial depression of Mola, separating the crystalline schists of the Mte. Calamita massif from those of the northern belt; before the erosion of that depression the two crystalline areas obviously formed one continuous complex.

(2) *The Granite Veins and Dykes.*—All round Cape Calamita, from Punta Pareti on the south-west coast to Punta delle Ripe Alte at the southern extremity, and thence along the east coast to Longone Bay and Cape Bianco at Terranera, the substratum of gneissic schists is intersected by innumerable veins of tourmaliniferous granite which constitute the most striking feature of this part of Elba. In some places, e.g. at Poggio Delfino in the south-eastern part of the Mte. Calamita massif, these veins project inland up to 300 m. above sea-level; in such classic localities as Punta delle Ripe Alte, the southern extermity already mentioned, or again at Cape Calvo at the base of Poggio Delfino, as also in Longone Bay near Mola and Porto Longone and towards Cape Bianco, the granitic veins become so predominant as almost to eclipse the gneissic, in some parts shaly brown schists.

Besides these veins, intrusive granite appears in the gneissic schists on the east coast in large dykes or masses, notably in the Mola depression, at Cape Bianco east of Longone, and on the left of the Mar di Carvisi glen in the locality called la Serra. In these cases

the granite is either of the normal and pegmatitic type with large felspar, often twin crystals, or it is micaceous, or again, contains microgranitic lenticular inclusions and apophyses of tourmaliniferous granite with fragments of gneissic schist. Near the iron deposits of Terranera in Longone Bay, the granite dykes in the gneissic schists are impregnated with iron and contain magnetite.

Although the contact line of the gneissic schists and the granite veins and dykes generally shows no marked alteration in either rock, the granite occasionally assumes a gneissiform schistose structure and appearance and vice versa. While many of the granite veins intersect the planes of the gneissic schists at acute or even right angles, others run parallel to those planes and then appear in the form of lenticular intercalations. This is notably the case in the Mola depression, where the gneissic schist is much laminated; again, on Poggio Delfino, where the granite intercalations alternate with quartz veins, and more especially at Punta delle Ripe Alte, where magnificent granite veins, containing fragments of gneissic schist, intersect, and also run parallel to the planes of the schist, which at the contact is partially altered to granite. The tourmaline of the granite veins is occasionally replaced by biotite, and vice versa; not infrequently the granite exhibits thin meandering microgranitic veins, as does the Mte. Capanne granite. Near Punta Pareti and Punta dell' Innamorata, on the south-west coast of the Calamita promontory, tourmaline also appears in microgranitic veins associated with quartz.

In marked contrast to the granitic veins and dykes in the gneissic schists, neither the white mica-schists of the western and central part of the Mte. Calamita massif, nor those of the belt from Cape Bianco to Cape Ortano on the coast north of Longone Bay, nor those of the Mar di Carvisi glen and Valdana exhibit any granitic veins at all. In all these mica-schists it is only quartz veins and intercalations that are conspicuous, as they are also in the sericitic schists of Capoliveri which form the uppermost or third horizon of the crystalline schist formation. Moreover, quartz veins and intercalations are frequent in the gneissic schists independently of the granite veins. They are, in fact, quite distinct from the latter and generally run parallel to the planes of schistosity, whereas the granite veins prevalently intersect the schists in all directions and often appear unaltered even where the latter are laminated and contorted. Like the granite veins, the quartz intercalations are often tourmaliniferous, the black tourmaline forming radially grouped aggregations along the edges of fissures filled with quartz.

The mineralogical composition of the granite both of the intrusive veins and the dykes and intercalations being the same, it follows that, like the granitic rocks of the Mte. Capanne massif, they are of the same submarine eruptive origin and of the same age of emergence, i.e. Post-Eocene, the granite of the veins and dykes having been forced up through transverse fissures, and that of the intercalations injected longitudinally between the planes of the gneissic schists.

(3) *Quartz-porphyry of the Capoliveri Hills.*—This small group of hills, on the coast of Stella Bay, forms the north-western part of the Mte. Calamita massif and is traversed by the bridle road leading from Valdana across the massif to Cape Calamita. It comprises Mte. Zuccale (144 m.) and the hill on which Capoliveri itself is built (200 m.), both of whose bases are deeply indented and on the land side surrounded by the alluvial deposits of the contiguous Mola depression between the Bays of Stella and Longone. The group forms a syncline and derives its geological interest mainly from the Upper Eocene beds and the masses of quartz-porphyry which are the only ones in the whole promontory of Mte. Calamita.

The masses of quartz-porphyry, crowning the two hills, overlie and are intrusive in the Eocene beds which on Mte. Zuccale rest on mica-schists and at Capoliveri on sericitic calcareous schists. It is noteworthy that the porphyry, apart from the dykes, forms veins in the Eocene strata, but not in the subjacent crystalline schists, a fact which shows not only that the porphyry masses and veins erupted in Post-Eocene times, but that their eruption was essentially in the nature of a superficial expansion. Both the sedimentary beds and the porphyry masses of the Capoliveri group must have formed part of the equivalent but larger group which lies north of the now intervening alluvial depression already mentioned and will be referred to in the sequel.

(4) *Quaternary Marine Deposits.*—A feature of additional interest in connexion with the Capoliveri group consists in the considerable Quaternary fossiliferous marine deposits both near the coast and on the inland flanks of the hills. These marine deposits, here as elsewhere in Elba, are composed of coarse, friable, calcareous sandstone, loose conglomerate of fragments and pebbles of neighbouring sedimentary and eruptive rocks, and notably of concretionary limestone called *panchina.* In other coastal parts of the island these deposits reach up to 50 or 100 m., but it is only in the Capoliveri hills that they are met with up to nearly 200 m. above sea-level, as they are on the coast of the mainland.

Immediately east of Capoliveri occur, in association with an Eocene outcrop, some traces of serpentine, probably in connexion with a ferrocalciferous deposit of the same locality. For the rest, as already stated, the whole Mte. Calamita massif is devoid of ophiolithic rocks.

(5) *Age of the Crystalline Schists.*—The three horizons of crystalline schists, i.e. the gneissic, the mica, and the mica-calc or sericitic schists of the Mte. Calamita massif, Longone Bay, and the Cape Ortano coast, together with the associated dolomitic and crystalline limestone series, were in 1886, and again in 1910, assigned by Lotti to the Pre-Silurian, in which he further included a band of schistose serpentine which on the Ortano coast immediately overlies the sericitic schists or *schisti plumbei.* This band of schistose serpentine, 4 km. in length and 100 to 200 m. in depth, is, in its turn, overlain

by a similar parallel band of carbonaceous schist which also extends further north along the coast from the Rio Marina and Vigneria iron-mines to Ripabianca. It was in the latter carbonaceous band that Lotti found *Orthoceras* and *Actinocrinus* fossils, on the strength of which he regarded the schist as Silurian, and therefore the subjacent schistose serpentine and the whole of the underlying non-fossiliferous crystalline schist and limestone series of the Ortano coast, and, by analogy, that of Longone Bay and of the Mte. Calamita massif, as Pre-Silurian.

But this classification, which had its *raison d'être* in 1886, appears, in my view, no longer tenable at the present time. Even before Lotti's work on Elba of that year, Savi, Meneghini, Coquand, and Cocchi had referred all those crystalline schists to the Carboniferous, the first two of those writers by analogy with the small Carboniferous deposit of Jano in the Tuscan Subapennines north of Siena,[1] the last two more especially by analogy with the gneissic, carbonaceous schists which form the substratum of the Apuan Alps. It was in the latter schists that Lotti and Zaccagna, in 1880, found *Orthoceras* and *Actinocrinus* fossils which Meneghini determined as Palæozoic. Later, in 1887, Zaccagna assigned the same Apuan schists to the Lower Permian or Permo-Carboniferous, on the strength of their close stratigraphical and lithological analogy with the besimaudite or apenninite formation of the Maritime Alps, and that age has since then been generally accepted.

But apart from these considerations, the Elban crystalline schists present a close analogy, both stratigraphical and lithological, with those of the Savona crystalline massif in Western Liguria, and, further, with those of the Cottian and Grajan Alps, that is with the great mica-schist and associated crystalline limestone and ophiolithic zone which runs along the western margin of the Po Valley and thence extends to the Val d'Aosta and to the Lanzo-Ivrea- and Val Sesia belt.[2] This mica-schist zone, which formed the middle horizon of Gastaldi's Archæan series, is now accepted as Permo-Carboniferous. As such it includes the gneissic schists and minute gneiss of the Piedmontese Alps as distinguished on the one hand from the Pre-Carboniferous glandular and eye-gneiss which constitutes the nuclei and substratum of the massifs of Argentera, Dora-Maira, and Gran Paradiso, and on the other hand from the Mesozoic calc-schist formation. These gneissic schists, like those of Savona and the Apuan Alps, and also those of Elba, often assume the structure and aspect of true gneiss with associated minute gneiss. In my view, the whole series of Lotti's Pre-Silurian gneissic, mica- and sericitic schists, with the associated dolomitic and crystalline limestone and cipollini, as well as the schistose serpentine and the overlying fossiliferous carbonaceous schist, in short the whole comprehensive

[1] *Vide* "The Permian and Triassic Belt of the Tuscan Subapennines", p. 3.

[2] The crystalline formations of the Piedmontese Alps and Western Liguria were described in previous papers, Part I of this volume.

crystalline schist and associated rock series of Elba, should be classed as Permo-Carboniferous, and thus synchronize with the equivalent crystalline formations of the Apuan Alps, Western Liguria, and Piedmont.

The granite veins and dykes intrusive in the gneissic schists but not in the upper crystalline schists are, as previously stated, identical and contemporaneous with the granitic rocks of the Mte. Capanne massif and, like the latter, emerged from a deep-seated submarine complex during the great general uprise in early Miocene times.

2. *The Northern Group.* (Figs. 1 and 6, pp. 159, 161.)

This group, the largest of the three eastern groups of Elba, covering about 50 sq. km., is composed of a remarkable sequence of crystalline, sedimentary, and ophiolithic rocks aligned in parallel zones north to south, dipping west. In its geological structure it differs materially from all the other parts of the island.

(1) *Palæozoic Zone : Crystalline Schists and Limestone.*—Proceeding from the coast of Ortano and Rio Marina up towards the parallel dividing ridge, the coastal belt of mica-schists without granitic veins, already referred to, is found to be overlain by an intermittent band of crystalline limestone and cipollini, followed by a continuous band of sericitic schists about 4 km. in length and 200 m. in thickness, all the three zones being a coastal extension of the Longone Bay and Mte. Calamita crystalline schist and limestone formations previously described.

Serpentine.—As already mentioned, the bank of sericitic schists is, in its turn, overlain by a remarkable bank of serpentine which, about 100 m. in thickness, rises to the 200 m. contour above sea-level, and runs from Rio Marina, where it descends close to the sea, for about 4 km. south along the flanks of Mte. Fico and Mte. Arco, crossing, about midway, the intervening glen of Rio Ortano. At its southern extremity towards Terranera, the bank dips unconformably below the Rhætian strata which here transgressively overlie the crystalline schists. The dark-green, peridotitic serpentine, without associated euphotide or diabase, is essentially schistose, often shaly, white-spotted, fibrous, and steatitic. In composition it does not differ from the Eocene serpentine and generally resembles the peridotitic schistose serpentine of Fetovaia, Marciana, and S. Piero of the Western Group. It is also essentially like the Triassic serpentine of Western Liguria, the Permian serpentine of the Maritime Alps, and more especially like the peridotitic serpentine masses of the Permo-Carboniferous mica-schist zone of the Piedmontese Alps.[1] It appears that it also resembles certain Pre-Tertiary serpentines of Eastern Corsica near Bastia and of Sardinia near Gonnari, as well as those of

[1] These serpentines of different ages and regions were described in previous papers. *Vide* Part I of the present volume.

the small outcrops in the islands of Gorgona and Giglio, and of Cape Argentario ; but in the three latter cases the serpentine appears in association with euphotide and diabase.

Carbonaceous Schist.—The bank of serpentine is directly and conformably overlain by, and interstratified with a narrow band not more than 50 m. in depth, of carbonaceous, arenaceous, spotted, dark violet to black schist, which runs parallel to the serpentine, and, like the latter, dips at its southern extremity near Terranera below the more recent strata. From Rio Marina north to Ripabianca for about 1 km. the same carbonaceous schist reappears as a narrow strip close to the sea. It is here that, as already mentioned, Lotti found the fossils which led him to regard this schist as Silurian, and the subjacent serpentine-crystalline schist and limestone series as Pre-Silurian. The reasons why the whole sequence should, in my view, be assigned to the Permo-Carboniferous were stated in a previous paragraph.

Permian Schists and Verrucano.—The carbonaceous schist is followed in upward succession by a Permian series of micaceous varicoloured schists and verrucano quartzites and conglomerates. This series, about 1 km. in greatest thickness, is largely developed along the coast from Rio Marina to Rio Albano and includes the iron deposits of those localities.

(2) *Mesozoic Zone : Rhætian and Lias.*—The Permian series is overlain transgressively by a Rhætian and Liassic bank 300 to 500 m. in thickness, which extends from the north-eastern extremity of the island, i.e. from Cape Castello all the way down to Longone Bay for over 10 km., the Middle and Lower Trias being absent.[1] The Upper Rhætian limestone strata are fossiliferous (*Bactryllium*, *Avicula*, etc.), the lower, mainly cavernous limestone, is in part crystalline, and rests unconformably upon the verrucano, while the upper strata are conformably overlain by Lower and Middle Liassic limestone, which is fossiliferous (*Arietites*), dark-grey, white, yellow, and reddish, in part dolomitic, in part subcrystalline. This limestone forms in the north-eastern part of the coast south of Cape Castello a cupoliform massif which comprises a cluster of conspicuously white and barren heights about 100 m. above sea-level, the most notable being Mte. Le Paffe close to the headland of that name.

The Upper Lias, composed mainly of varicoloured argillaceous schists with *Posidonomya Bronni*, and intercalations of compact limestone, rests unconformably not only on the other Liassic strata but in the narrow zone towards Longone Bay, also direct on the Rhætian, Permian, and even on the older crystalline schists. This transgressive discordance points to the Liassic period having been one of emergence and subsequent erosion.

[1] Cocchi, in his work on Elba (op. cit.), regarded the cavernous limestone as Middle Triassic and the underlying verrucano as Lower Triassic ; but these formations are now, by analogy with the Apuan Alps and the Tuscan Subapennines, classed as Rhætian and Upper Permian respectively.

(3) *Tertiary Zone.*—In the apparent absence of Cretaceous beds,[1] the Upper Lias is directly overlain by the Eocene sedimentary formation, which, together with a large infolded ophiolithic zone, reaches up to the crest or divide of the eastern watershed and also occupies the whole western watershed of this part of Elba. Its general direction is north to south, dipping west. The Palæozoic, Mesozoic, and Tertiary formations of the eastern watershed, aligned in parallel, consecutively superposed zones from the sea to the crest of the divide, from 400 to 500 m. altitude in a distance of 2 to 4 km., may be conveniently studied in the short, but deeply cut, fjord-like glens, notably in those of Terranera, Ortano, and Rio Marina, in which all the formations are exposed in upward succession. Here, as elsewhere in the island, alluvial, and patches of Quaternary marine deposits reach inland to a considerable distance from the sea, the latter deposits being in evidence more especially near the north-eastern extremity at Cala Volbiana, immediately south of Cape Castello.

The Ophiolithic Group.—The Eocene sedimentary and ophiolithic formations occupy all the eastern upper flanks and the crest of the range of hills formed by Mte. Grosso, Strega, Capannella, Volterraio, Cima del Monte, and Mte. Castello above Longone, at altitudes increasing from 350 to 516 m. in Cima del Monte, and thence again decreasing to 390 in Mte. Castello. The ophiolithic zone on the eastern flanks, often in contact with the Upper Lias, extends in intermittent narrow bands from Mte. Grosso near the Cape Cavo promontory, the extreme northern point, to Rio Alto (125 m.) above Rio Marina, and thence expands to a large continuous area which reaches south to Porto Longone and west to the Ottone spur in Portoferraio Bay.

In the northern bands, notably at Mte. Peritondo and Mte. Lecciolo, the ophiolithic masses are mainly composed of lherzolitic serpentine with some diabase, of which an isolated mass of a coarse-grained variety with some euphotide appears also on the west coast between Punta dei Mangani and the Nisportino glen; but on the eastern flanks from Rio Alto—which place is built on serpentine—southwards the ophiolithic area comprises serpentine, euphotide, and diabase in the usual succession, the euphotide forming only a narrow band and some isolated masses between the other two rocks, of which diabase is the largely predominant. All the three rocks are of the characteristic Tuscan Eocene type previously described; of the euphotide a remarkably fine outcrop appears immediately above Longone at the southern extremity of the ophiolithic area. The diabase of the three masses of Mte. Mar di Capanna above Longone on the eastern, of the Botro glen on the southern, and below Volterraio on the western flanks of Mte. Castello are often spheroidal,

[1] The Eocene series of Elba was formerly classed as Cretaceous by various authors, but the occurrence of nummulitic limestone as its lowest member proves it to be Eocene.

epidotiferous, and decomposed to pseudo-serpentine schist. These masses almost encircle the sedimentary Eocene nucleus of Mte. Castello, on whose western flanks the diabase mass is in close proximity to, but separated by a sedimentary strip from, the belt of quartz-porphyry and micro-granite to be referred to later.

The ophiolithic zone of the north-eastern group covers an area of about 12 sq. km. equal to that of Mte. Orello in the central group. The Eocene, mainly lherzolitic serpentine of both these groups, often schistose, altered and decomposed, but without contact-phenomena in relation to the overlying euphotide and diabase, in no way differs from the older peridotitic rock which forms part of the Palæozoic series, except that the latter is more crushed, schistose, and often shaly, and the former is more pyroxenic. The road from Porto Longone to Rio Alto, which follows the contour-lines of the eastern flanks of the hills about 100 to 150 m. above sea-level, runs almost entirely in the Eocene serpentine band and thus affords numerous exposures of the ophiolithic series of this part of Elba.

The Diaspri Formation.—On the eastern flanks the ophiolithic group rests on an intermittent band of Lower Eocene nummulitic limestone, while on the crest and on the western flanks it is in part overlain by a remarkable Middle Eocene formation of red diaspri which constitutes the characteristic feature of this part of the island. These silicified, indurated, semi-crystalline, prevalently dark-red, but also yellow and green limestones, with which are occasionally associated indurated, more argillaceous ftaniti, contain innumerable microscopic remains of radiolaria and are in all respects the equivalents of the diaspri of Tuscany and Eastern Liguria, where, as in Elba, they occur in close contact and association with ophiolithic rocks, more especially with diabase.

The Elban diaspri formation constitutes the greater part of the crests and western flanks of Mte. Strega, Capannella, Volterraio, Cima del Monte, and Mte. Castello previously mentioned, where it reaches a vertical depth of at least 250 m., and by the rugged, peaked, essentially barren and alpine character and its deep-cut precipitous gullies and ravines presents a striking contrast to the softer outlines of the surrounding sedimentary and ophiolithic hills. In the northern part, near Mte. Grosso, it appears only in isolated outcrops but invariably near or in contact with ophiolithic rocks to which it runs parallel for about 10 km. south all the way towards Longone. The diaspri share with the diabase masses a marked tendency to thinning out at both ends of their principal areas, and both are therefore of an essentially lenticular character. Although generally contiguous, or in some places alternating with, in others, again, intercalated in each other, the contact of the two rocks is always distinct and the superposition perfectly conformable.

Near the old castle of Volterraio (394 m.) on the bridle-path from Portoferraio Bay to Rio Alto, the diabase in contact with diaspri assumes a markedly globular, amygdaloidal structure with diabasic

lumps embedded in a greenish steatitic paste. Again, a short distance below Volterraio on the western side, the diabase in contact with diaspri is altered to pseudo-serpentinous schist. In other outcrops, e.g. at Cala d'Ottone in Portoferraio Bay, the diabase of the ophiolithic spur is, in contact with diaspri, nodulous, steatitic, and in part reduced to a conglomerate. These alterations of the diabase on the one hand and the induration of the limestone to diaspri on the other are the only contact-phenomena in the two superposed rocks.

The Botro glen and that of Monserrato on the southern flanks of Mte. Castello exhibit greatly contorted, often vertically tilted masses of diaspri which overlie the diabase and are, in their turn, overlain by Eocene compact, greatly folded and disturbed limestone. In another part of the Botro glen diabase is seen to rest, without the interposition of Eocene strata, direct on Palæozoic schist, with an intervening strip of dark-green shaly, pasty schist, i.e. diabase converted to schist by pressure. Owing to the close association of diabase and diaspri, the latter have sometimes been classed as ophiolithic rocks ; that can, however, only apply to the so-called ophicalce, i.e. crystalline limestone with ophiolithic veins or impregnations. As regards diaspri, the presence of radiolaria precludes their being more than indurated limestone. Their silicification is probably due to submarine silico-ferruginous springs which issued from contiguous hydrated diabasic expansions infolded in the plastic sedimentary planes. The folds and flexures of the diaspri formation are probably more recent than, and independent of, the ophiolithic masses, for they occur throughout the principal area, i.e. even at a distance from those masses.

The diaspri pass to ordinary compact varicoloured limestone which is largely developed on the lower western flanks along the coast. In the northern part, this yellowish, green, and red limestone forms the headland of Mte. Cavo, then Mte. Grosso and the coastal belt from Punta Nisporto to Punta Pina in Portoferraio Bay. As already mentioned, it also forms part of the western flanks of Cima del Monte and Mte. Castello in the Acquacavalla glen, where it overlies the diaspri, and is, conformably with the latter, greatly folded and contorted. The two rocks are so intimately correlated, and their colour varies so equally and constantly according to the degree of ferruginous infiltration that they are obviously identical, one being a silicified modification of the other. As already stated, this silicification is, here as elsewhere, the effect of the ophiolithic eruption and expansion in the Eocene sedimentary horizon ; but in the Elban rocks the process took place on so phenomenal a scale that the limestone area thus affected is quite as large as that of the ophiolithic masses, and of enormous depth.

3. *The Valdana Group.* (Figs. 1 and 7, pp. 159, 161.)

As previously mentioned, the low hills of Mte. Fabbrello and Valdana in the depression between the Bays of Portoferraio and

Stella constitute a specially important part of Eastern Elba. The Valdana torrent, which rises not far from the low saddle of Mte. Fabbrello (125 m.) and discharges into Stella Bay, divides the depression into two sharply-marked parts : one on the right, along the base of the ophiolithic massif of Mte. Orello ; the other, on the left, along the low hills at the base of Mte. Castello. The group on the right is composed of a series of parallel, superposed bands, about 150 m. in total thickness, and 3 km. in total length, of Palæozoic and Mesozoic rocks, while the group on the left consists of Upper Eocene strata with a belt of quartz-porphyry and microgranite. In the lower part of the valley near Stella Bay, both groups are in contact with the white mica-schist zone without granitic veins of the coastal belt of that Bay and Capoliveri.

The Group on the Right.—The parallel bands referred to are in composition, sequence, and axial direction north to south an exact replica, albeit on a smaller scale, of the group on the east coast from Terranera to Ortano Bay and Rio Marina, i.e. they are composed, in upward succession, overlying the white mica-schists, of cipollini and crystalline limestone, sericitic schists, schistose serpentine in some intermittent outcrops, Permian schist and conglomerate, and Rhætian and Liassic limestone, the last-named in contact with the ophiolithic masses of Mte. Orello. The white-mica schist, forming part of the larger complex of the Mte. Calamita and Capoliveri area, is not in an abnormal position ; but the position of the other rocks in six parallel superposed bands seems *prima facie* unintelligible, the more so as on Mte. Fabbrello the carbonaceous schist appears in unconformable juxtaposition to the Upper Eocene sedimentary strata of the group on the eastern side of Valdana (Fig. 7). Lotti has explained this anomalous juxtaposition by a fault.[1] The fault undoubtedly exists ; but it does not explain the anomalous position of the group of parallel bands, which can only be due to a local displacement anterior to the fault. By this Pre-Tertiary displacement, the group in question must, in my view, have been transported about 5 km. from the east coast to its present position in the Valdana depression. The displacement occurred probably during the slow and partial emergence towards the end of the Liassic period.

The Group on the Left.—The Eocene and porphyry group on the left of Valdana, much folded and disturbed, is also in an anomalous position. It forms a syncline which on Mte. Fabbrello and all along the Valdana fault abuts discordantly against the Palæozoic schists on the right side of the depression (Fig. 7). The sedimentary Eocene is here composed entirely of the upper or promiscuous horizon, i.e. of macigno sandstone, galestri schist, and albarese limestone superposed, not in regular sequence, but promiscuously. This horizon appears normally only in the western and central parts

[1] Op. cit., 1886, p. 28 ; ibid., p. 137 ; also op. cit., 1910, p. 386, and Boll. R. Com. geol., 1910, p. 284. "Ipotesi del Termier sulla Tettonica dell'Elba."

of Elba, and abnormally in the eastern part in Valdana and at Capoliveri. The same applies to the quartz-porphyry with associated micro-granite which in the Valdana, as in the Capoliveri group, forms considerable masses in part overlying the sedimentary strata. In the former group it constitutes in fact a semicircular, peripheral belt 3 km. in length and up to 100 m. in thickness, which, at about 200 m. altitude, is tilted against the Middle Eocene limestone formation and the ophiolithic masses on the western flanks of Mte. Castello. It extends even into the Mar di Carvisi glen, and here closely approaches, though it is not in actual contact with, the gneissic schists and granite dykes of the belt of Longone Bay. As previously pointed out, the two Upper Eocene and porphyry groups of Valdana and Capoliveri, now separated by the Mola depression between the Bays of Stella and Longone, obviously formed originally one continuous area. Their anomalous position is probably due, as Lotti has also suggested,[1] to their having been displaced W. to E. from the great central group of the island in connexion with the fault already mentioned (Fig. 7). Lotti apparently restricts this fault—whose existence was pointed out by Reyer [1] as early as 1884—to Mte. Fabbrello ; it extends, however, from that saddle southward along the Valdana depression to Stella Bay, its axis being marked by the course of the Valdana torrent. But that fault and the consequent displacement W. to E. referred to could only be Post-Miocene, i.e. posterior to the Pre-Eocene displacement E. to W. of the group of Palæozoic and Mesozoic bands on the right of Valdana.

Thus the two groups of the Valdana depression, one on the right, the other on the left side of the valley, are, in my view, the result of two local displacements or overthrusts of about 5 km. each, in opposite directions and at different periods, and the combined area of the whole synclinal depression lies in a zone of Post-Miocene subsidence.

V. The Geological Structure.

From the foregoing description of the three main divisions of Elba it will be seen that while each of them has its own characteristic, often complex features which in many respects present striking contrasts, the geological structure of the island as a whole is comparatively simple.

The western division, i.e. the great granitic massif of Mte. Capanne with its marginal girdle of sedimentary, metamorphic, ophiolithic, and porphyritic rocks, presents the structure of a normally upraised dome-shaped, laccolitic complex. Similarly, the south-eastern group of the eastern division, comprising the Palæozoic crystalline schist- and limestone areas of Mte. Calamita, constitutes a normally cupoliform massif. Again, the north-eastern group of the same division forms an ellipsoidal anticline which exhibits in generally concordant superposition the whole Elban Palæozoic and Mesozoic

[1] E. Reyer, "Aus Toskana," Wien, 1884.

series in normal sequence aligned N. to S., dipping generally W., and crowned by the Eocene sedimentary horizon with ophiolithic masses. In both the western and eastern divisions, the various formations exhibit here and there considerable folding, flexures, and contortions, but very little and only insignificant faulting. The stratigraphical unconformities and transgressions of some of the Mesozoic and Tertiary sedimentary formations on the north-east coast are, except in the case of the Upper Lias, more apparent than real, for they are mainly due to the largely lenticular character of the formations thus affected.[1] The only division which exhibits marked disturbances more or less throughout its area is the central one, together with the adjacent and closely correlated Valdana group, though the latter forms, strictly speaking, part of the eastern division. As previously shown, the disturbed and complex, in places confused stratigraphical condition of the central division is due in the first instance to the intrusion of the great porphyry masses in the Upper Eocene formation. Again, the abnormal geological structure and stratigraphical condition of the adjacent Valdana depression together with the Capoliveri group is the result of two local displacements, and in part to the fault from Portoferraio Bay to Stella Bay, the only important fault in the whole island. As already stated, the Valdana depression lies, in my view, in a Post-Miocene subsidence zone, and the same applies in a wider sense to the whole central division as an area of subsidence compressed between the western and eastern divisions of the island.

Elba thus presents in all its essential tectonic features a succession of crystalline and sedimentary formations built up in situ on an extensive, deep-seated granitic substratum.

The Exotic Overthrust Theory.

Fundamentally different from the foregoing tectonic interpretation is that advanced by Termier in his Memoir, already quoted, of 1910.[2] Following up his own and Maury's views in favour of extensive overthrust phenomena in Corsica,[3] he endeavours to show that analogous phenomena are in evidence in Elba, which island he therefore characterizes as essentially a *pays de nappes*, i.e. a region of overthrust sheets. His elaborate and ingenious, but essentially *a priori* argument may be briefly stated as follows :—

Overthrust Series.—The gneissic and the white mica-schists of Eastern Elba are predominantly mylonites, i.e. laminated, crushed, brecciated, bruised, and mashed microgranite reduced to a chaotic condition by the friction of crystalline, sedimentary, and ophiolithic

[1] The Middle and Lower Trias and the Cretaceous are not represented in Elba ; with few exceptions they are also absent in the neighbouring Tuscan littoral.

[2] Op. cit., 1910.

[3] P. Termier, "Rapports tectoniques," etc. : Bull. Soc. géol. France, 1907, p. 421. P. Termier et E. Maury, "Sur les nappes de la Corse orientale" : Compt. Rend. Ac. Sc., cxlvi, p. 1426.

masses which passed over those schists in the manner of *traîneaux écraseurs*. Hence the surface of those schists—which, together with other associated rocks, form the apparently or *quasi*-fixed, autochthonous substratum—constitutes a transport- and friction-surface on which the transported masses were deposited as overthrust-sheets. The substratum itself was not originally rooted, i.e. in situ, but was subterraneously transported E. to W. from an exotic source, i.e. from the Dinarides; apparently it is now worn-out (*fatigué*) and fixed, but may still be slowly moving towards W. On the other hand, the masses which passed over, and were deposited on the friction surface of the substratum, were pushed over in the opposite direction, i.e. W. to E., one complex being derived from Eastern Corsica, the other from the western part of that island.

Elba is thus, in Termier's view, composed of three, i.e. lower, middle, and upper, overthrust series, which are separated from each other by friction-surfaces as evidence of their being transported areas, i.e. having no roots in Elba. The outcrops of these friction-surfaces form, according to Termier, an intermittent, meandering line which indicates the juxta- or superposed contact of the three series, and thus defines the areas of the series themselves. The middle and upper, i.e. Corsican series, are confined to parts of the central and north-eastern groups of Elba; they jointly or separately overlie, or, in Termier's phraseology, *flottent*, i.e. float on, the substratum series, which latter extends to and comprises all the rest of the island.

The three series may be summarized as comprising respectively the following formations:—

I. *The Lower Series*, substratum transported subterraneously E. to W. from the Dinarides (500 km.), now apparently fixed, or moving slowly towards W.

(*a*) The mylonitic, crystallo-phyllienne horizon: the Palæozoic laminated and crushed gneissic and mica-schists of Calamita Valdana, Longone Bay, and the coastal belt Terranera-Ortano Bay.

(*b*) The crystalline, dolomitic, Palæozoic limestone of Calamita, Capoliveri, and Valdana; the Upper Eocene and quartz-porphyry groups of Capoliveri and Valdana.

(*c*) The granitic, metamorphic, sedimentary, ophiolithic, and porphyritic, Eocene and Miocene groups of Western, and the Eocene and quartz-porphyry of Central Elba.

II. *The Middle Series*, transported W. to E. from Eastern Corsica (60 km.): metamorphic series (*schistes lustrés*): sericitic calc-schist of Capoliveri and the Ortano coast; banded crystalline cipollini, and schistose serpentine of Valdana and the Ortano coast, comprising Upper Trias to Eocene.

III. *The Upper Series*, transported W. to E. from Western Corsica (150 km.), is deposited on series I or II, and continues to the Tuscan mainland: non-metamorphic series: the Palæozoic, Mesozoic, and Tertiary groups (carbonaceous schist, Permian,

Rhætian, Lias, Lower and Middle Eocene), also the ophiolithic groups of North Eastern Elba, of Valdana, and of Portoferraio, Mte. Orello, and Cape Stella.

It is at once apparent that these series, governed exclusively by the contact lines of the presumed friction- or contact surfaces, are, by the exigencies of Termier's theory, more or less artificially constituted, i.e. irrespective of age and so as to accord more or less with the exotic areas from which he considers them to be derived. The lower (I) series, i.e. the gneissic, mica-schist, and granitic substratum of presumed Dinaric origin, like that of the crystalline massif of Savona, includes great Eocene, ophiolithic, and quartz-porphyry masses which, unless they were picked up on the way, must have been deposited on the substratum in situ, i.e. after it came to apparent or *quasi*-rest in Elba. The metamorphic formation of the middle (II) series, i.e. the mica-schists and cipollini, as also the schistose peridotitic serpentine which stratigraphically belong to the Elban Palæozoic horizon, are by Termier assimilated to the East Corsican Liassic *schistes lustrés*. Again, the upper (III) series is made up of all the non-metamorphic formations from the Palæozoic to the Middle Eocene, presumed to have been transported from Western Corsica, albeit that region is now devoid of those rocks, and is only crystalline. In short, in order to establish the three overthrust series, the superposition of the various formations has often to appear abnormal when in reality the stratigraphical sequence and conditions are, with few exceptions, essentially normal.

The Friction and Transport Surfaces.—The meandering contact-line which, according to Termier, marks the friction surfaces of the three series at the points of their abnormal superposition, is about 25 km. in length and lies mainly in the Eocene formation between the Bays of Portoferraio, Acona, and Stella, whence it runs along the Palæozoic horizon of the Longone and Ortano coast. Starting from the Eocene ophiolithic and quartz-porphyry outcrops with intervening breccia at Le Ghiaie, immediately west of Portoferraio, the line runs south over Colle Reciso and across the island to Acona Bay, thence east to Stella Bay, and from there north again along the Valdana depression to Mte. Fabbrello. From this point it turns south-east, running up the Acquacavalla glen along the base of Mte. Castello and thence down to Longone Bay. From here it extends east to Terranera, and thence along the north-east coast to Ortano Bay and Rio Marina.

In the first part, between Colle Reciso and Mte. Castello, the line lies, with the exception of Valdana, almost entirely along the contact of the Upper and Middle Eocene horizons. The strips of brecciated and crushed rock between them which Termier interprets as friction surfaces, are simply the result of ordinary folding and contortion in the course of repeated earth-movements, and the same applies to the occasional, apparently abnormal superposition of the lower series (III) on the upper series (I) in the sometimes vertical, in places even reversed flexures. The presumed abnormal superposition is, in

fact, essentially a juxtaposition of the two horizons, precisely as it is in the case, already mentioned, of the Palæozoic carbonaceous schist and the Eocene of Mte. Fabbrello, and thence all along the Valdana fault to Stella Bay. Moreover, Termier's contact-line lies mainly in depressions which, as previously pointed out, form, in my view, part of a zone of local displacement and subsidence in this part of Elba. Again, on the north side of Longone Bay and along the north-east coast, the superposition of the formations, i.e. the non-metamorphic series (III) on the white mica-schist series (I) with the so-called metamorphic *schistes lustrés* series (II) between them, is not abnormal. Any apparent abnormality resolves itself either to a juxtaposition or is due to the transgressive superposition which, as already mentioned, occurs at several points of North Eastern Elba.

The presumed friction surfaces are, moreover, by no means continuous but appear only at certain points of the contact-line as indicated by Termier. Even at these points the friction surfaces are in part admittedly hypothetical. The presumed abnormal superposition of the three series is in fact to a great extent the logical consequence of their artificial constitution irrespective of the age and normal sequence of the formations.

The Mylonitic Horizon.—As the presumed abnormal superposition of Palæozoic schist on the Upper Eocene on Mte. Fabbrello is, in Termier's view, *le noeud* of Elban geology,[1] so do the gneissiform mica-schists of Valdana constitute, in his own words, " les plus beaux examples " of mylonites he has ever seen.[2] His mylonitic horizon comprises, as previously stated, all the gneissic and mica-schists of the Mte. Calamita massif, Longone Bay, the north-east coast, and Valdana ; but it is in the last-named depression, i.e. in a small quarry south of Mte. Fabbrello, near the Longone road, that he finds the most typical example of mylonite as laminated, crushed, and mashed microgranite.

The gneissiform, pale reddish schist in question is macroscopically in part schistose, in part aphanitic, with scales of sericite, partially kaolinized, tourmaliniferous, and unquestionably derived from a granitic or porphyritic rock. Microscopically it reveals two associated structures, one of a sericitic schist and the other more aphanitic and porphyroidal, according to the degree of lamination. The holocrystalline groundmass is composed of quartz and sericite with micro-phenocrysts of quartz and orthoclase. In this groundmass all trace of the original structure has disappeared ; it shows no trace of broken-up micro-crystals ; the only accidental micro-crystals are zircone and tourmaline, and thin aggregations of secondary quartz along the planes of schistosity. The rock is essentially a secondary

[1] Op. cit., 1910, p. 144. As already mentioned, the unconformable contact of the carbonaceous schist and the Eocene strata is not an anomalous superposition of the older on the younger rock, as Termier contends, but a discordant juxtaposition of the two, due to the Mte. Fabbrello fault.

[2] Op. cit., 1910, p. 138. In even more glowing terms Termier described the presumed mylonites of Savona in 1912.

sericitic schist or so-called porphyroid, derived from granitic porphyry.[1]

Termier, on the other hand, emphasizes the still perceptible micro-granitic structure of the groundmass as showing its derivation from microgranite,[2] while in the white gneissiform mica-schists of the north-east coast—Termier's *fauxgneiss*—the groundmass is converted to a secondary quartzose sericitic schist, the original quartz having entirely disappeared. Termier's contention that the Valdana schist is derived from microgranite is, however, invalidated by the fact that not far from the quarry, i.e. on Mte. Puccio and also on Mte. Fabbrello occurs microgranite associated with quartz-porphyry which, being on the very contact-line of the presumed friction surfaces, should also be, but is not mylonitized. In any case, whether the Palæozoic gneissiform schist, which contains 75 per cent silica, be derived from granite, quartz-porphyry or microgranite, the parent rock obviously cannot have been any granitic rock of Tertiary emergence. The same applies to the gneissic and mica-schists of Mte. Calamita, Longone Bay, and the north-east coast. All these Palæozoic schists must be recognized as the secondary products of originally granitic rocks laminated, crushed, and altered under pressure. But this does not constitute evidence of the existence of a mylonitic horizon produced in Tertiary times by overthrust-sheets passing over the substratum.

As already mentioned, Termier's presumed friction surfaces are limited to the narrow region between the Bays of Portoferraio and Stella and along the north-east coast of Elba. But as his Corsican overthrust sheets (series II and III) must first have passed over the great western and central granite and quartz-porphyry massifs of Mte. Capanne and Mte. S. Martino, these, too, should exhibit conspicuous evidence of friction by transport, whereas their surfaces are only worn by atmospheric action.

Mainland Extension of Overthrusts.—According to Termier the over-thrust sheets of Corsican origin (II and III) extended their easterly course beyond Elba to the Tuscan Subapennines, as witness the Permian, Rhætian, and Liassic outcrops or " windows ", as well as the great Eocene sedimentary and ophiolithic areas of that region. The presumed Dinaric substratum (I), too, is stated to have marked its passage east to west by leaving behind some parts of its constituents, e.g. the granitic outcrops of the Tuscan littoral as well as the Upper Eocene sedimentary areas. Any anomalies, modifica-tions, or fundamental changes in the composition of the areas thus transported from Corsica to Elba and Tuscany or vice versa are attributed to some formations having been dropped, others picked up

[1] P. Aloisi, " Roccie granitiche della parte orientale dell' Elba " : Atti Soc. tosc. sc. nat., 1910. V. Novarese, " Il presunto piano milonitico dell' isola d'Elba " : Boll. R. Com. geol., 1910, p. 292. Aloisi's micro-analysis of the granitic rocks of Valdana, Mar di Carvisi, Picro in Campo and Longone preceded Termier's memoir of the same year.

[2] Op. cit., p. 136.

en route. I have already shown in preceding papers [1] that in the Tuscan Subapennines all the evidence points to the formations referred to having been built up in situ.

Age of Overthrusts.—The geological period to which the presumed overthrusts are referred is not stated; possibly Termier considers them contemporaneous with the presumed overthrusts in the Savona region of Western Liguria, i.e. Oligocene; but considering that the Elban overthrust sheets include not only the Upper Eocene sedimentary horizon but the Miocene granite and quartz-porphyry massifs, the see-saw transport of the three series would have to be assigned to a much more recent period. Thus the question of age only adds to the inherent anomalies of the theory as applied to Elba.

Termier's theory of the geological structure of Elba being due to exotic overthrusts impelled by dynamic forces in opposite directions and overlapping and floating on each other is unquestionably bold, attractive, and expounded by him with all his ability and enthusiasm. But it is, like the same theory applied by him to the Savona crystalline massif, essentially speculative and hypothetical, and the evidence he adduces in support of his *a priori* argument is inconclusive and unconvincing. Nothing indeed could be more striking than his own admission concerning his presumed three overthrust series: *Nous ne savons pas ce qui a bougé et ce qui est resté tranquille.*[2]

VI. Conclusion.

1. All the tectonic phenomena of Elba show the island to be composed of a sequence of formations normally built up in situ, i.e. without the agency of exotic overthrusts. The only cases of overthrust are the two purely local displacements in the Valdana group. The existence of identical or equivalent formations in regions now separated by the sea, like Elba and the Tuscan mainland on the east, and Corsica on the west, is *per se* no proof of extensive overthrusts, but points to these regions having been formerly connected by land as a continent.

2. In the stratigraphical sequence of Elba, the Palæozoic gneissic and mica-schists, the crystalline dolomitic limestone and the sericitic calc-schists,[3] as well as the black carbonaceous schist and the schistose peridotitic serpentine of the eastern part and the Valdana group, hitherto assigned to the Pre-Silurian and Silurian, should be classed as a comprehensive Permo-Carboniferous series by analogy with the equivalent series of the Apuan Alps, Western Liguria, and the Piedmontese Alps.

[1] "The Permian and Triassic Belt" and "The Ophiolithic Groups of the Tuscan Subapennines."

[2] Op. cit., 1910, p. 153.

[3] Termier regards the sericitic calc-schists as *schistes lustrés*, i.e. as Triassic-Liassic; but on the Ortano coast they are overlain by the carbonaceous schist (Orthoceras and Actinocrinus) and cannot, therefore, be more recent than the latter.

3. The island rests on a great deep-seated granitic substratum which extends in a radius of 50 km. to the other islands of the Tuscan archipelago, to the Tuscan littoral on the east, to Corsica on the west, and over 150 km. north to the Savona Hills of Western Liguria. In Elba this substratum was raised in Tertiary times to over 1,000 m. above sea-level in the granite massif of Mte. Capanne, and to nearly 400 m. in the quartz-porphyry massif of Mte. S. Martino, and also injected veins and dykes into the gneissic schists of the eastern groups, which latter were raised to over 500 m. above sea-level. The Palæozoic gneissic schists with associated minute gneiss, as well as the overlying mica-schists, are probably themselves derived from the granitic substratum by submarine lamination and crushing under pressure before their emergence.

4. The principal earth movements which affected Elba and the rest of the archipelago as well as the Tuscan littoral and Subapennines may be summarized as follows :—

(1) *Pre-Eocene.*—Local displacement of Palæozoic and Mesozoic strata in Elba from the north-east coast to Valdana.

(2) *Early and Middle Eocene.*—Submarine eruptions of ophiolithic groups of Western, Central, and Eastern Elba and in Tuscan Subapennines.

(3) *Later Eocene-Miocene.*—Great general uprise of Tyrrhenean Continent and Tuscan Subapennines ; connexion between Tuscan littoral, Elba, and Corsica.[1] Uprise of eruptive granitic, porphyritic, and microgranitic masses of Elba, Montecristo, Giglio, Campiglia, and Gavorrano.

(4) *Miocene-Pliocene.*—Partial subsidence of Tyrrhenean Continent reduced to archipelago. Miocene and Pliocene formations submerged. Formation of ferriferous and ferro-calciferous deposits in Elba. Fault of Mte. Fabbrello. Local displacement of Eocene and quartz-porphyry masses from Central Elba to Valdana depression and Capoliveri.

(5) *Early Quaternary.*—Second uprise of archipelago and Tuscan littoral ; increase of insular areas of archipelago and extension of marine deposits.[1]

(6) *Middle Quaternary.*—Second lowering of archipelago and Tuscan littoral ; Quaternary marine deposits partially submerged. Subaerial eruptions of Tuscan trachyte groups of Mte. Amiata, Radicofani, Roccastrada, Campiglia, Montecatini, and island of Capraja.

(7) *Recent Quaternary.*—Third uprise of Elba and Tuscan littoral. Quaternary marine deposits raised 200 m. above sea-level.

The great Miocene uprise—" la grande striction tertiaire " as Termier aptly calls it—was effected in the Tyrrhenean and Tuscan

[1] The existence of a Miocene Tyrrhenean Continent, as well as the variations of the archipelago posterior to the intervening subsidence, rest not only on geological, but also on biological grounds, as shown by C. L. Forsyth-Major in his " Dies Tyrrhenis ", 1883.

littoral regions by three great concentric thrust-folds, whose thrust centre lay in Northern Corsica, and which, as shown in a previous paper,[1] formed Elba as part of the Tyrrhenean Continent, and the two belts of the Tuscan Subapennines. The more recent earth-movements in Elba and the archipelago produced only minor oscillations of alternate raising and lowering by a few hundred metres, evidenced chiefly by the variations of the Quaternary marine deposits above sea-level. The present phase points, if anything, to a slow raising of those deposits, and therefore of the coast-line.

In all the Tertiary and Post-Tertiary phases of its geological history Elba has shown its intimate correlation with the Tuscan Subapennines, while Corsica and Sardinia exhibit more geological affinity with the coastal regions of Southern France and Eastern Spain. In mere superficial area Elba is of course much smaller than either of those two islands, but in the unique, concentrated variety and the absorbing interest of its three constituent parts it is *facile princeps* and the geological gem of the Mediterranean.

[1] "The Permian and Triassic Belt of the Tuscan Subapennines."

APPENDIX.

N.B.—The numbers refer to the papers in which the authors are quoted.